# Semiannual water column monitoring report

## July - December 2001

Massachusetts Water Resources Authority

Environmental Quality Department
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# SEMIANNUAL WATER COLUMN MONITORING REPORT

## July – December 2001

**Submitted to**

**Massachusetts Water Resources Authority**
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# EXECUTIVE SUMMARY

The Massachusetts Water Resources Authority (MWRA) has collected water quality data in Massachusetts and Cape Cod Bays for the Harbor and Outfall Monitoring (HOM) Program since 1992. This monitoring is in support of the HOM Program mission to assess the environmental effects of the relocation of effluent discharge from Boston Harbor to Massachusetts Bay, which occurred on September 6, 2000. From 1992 to September 2000, data were collected to establish baseline water quality conditions. The current outfall monitoring is expected to provide the means to detect significant departure from that baseline. The surveys have been designed to evaluate water quality on both a high-frequency basis for a limited area in the vicinity of the bay outfall site (nearfield) and a low-frequency basis over an extended area throughout Boston Harbor, Massachusetts Bay, and Cape Cod Bay (farfield). This semi-annual report summarizes water column monitoring results for the ten surveys conducted from July to December 2001.

Over the course of the HOM program, a general trend in water quality events has emerged from the data collected in Massachusetts and Cape Cod Bays. The trends are evident even though the timing and year-to-year manifestations of these events are variable. The summer is generally a period of strong stratification, depleted nutrients, and a relatively stable mixed-assemblage phytoplankton community. In the fall, stratification breaks down supplying nutrients to surface waters that often results in the development of a fall phytoplankton bloom. The lowest dissolved oxygen concentrations are usually observed in the nearfield in October prior to the fall overturn of the water column. By late fall or early winter, the water column is usually well mixed and has returned to winter conditions. In 2001, there was a delay in the deterioration of stratification as the water column remained at least weakly stratified until late December and this led to the development of a late fall/early winter bloom and a seasonal peak in production rates and chlorophyll concentrations in early December.

The delay in the overturn of the water column and the return to winter conditions was the primary physical characteristic of this period. In the nearfield, mooring data indicated that there was a strong mixing event in late September, but by early October both the mooring and nearfield monitoring data indicated the water column had restratified. A weak density gradient continued to be observed from late October to early December. The water column finally returned to well-mixed winter conditions over the entire nearfield in late December. Mild meteorological conditions contributed to the lingering stratification into early December.

The general trend in nutrient concentrations during July to December 2001 was similar to previous baseline monitoring years. Nutrients were depleted in the surface waters during the summer due to biological utilization and increased in concentration with weakening stratification and increased mixing. The extended period of weak stratification from October to December provided a source of nutrients to the surface waters due to weak mixing and allowed for phytoplankton to bloom. The combination of limited mixing and the late fall/early winter bloom kept surface water nutrient concentrations relatively low until the water column became well mixed in late December. Ammonium continued to be an excellent tracer of the effluent plume in the nearfield although it is not a conservative tracer due to biological utilization. In August 2001, salinity and $NH_4$ data suggested the effluent plume was advected from the nearfield to the south. A comparison of $NH_4$ and chlorophyll concentrations in the vicinity of the plume suggest this source of nitrogen may have contributed to localized increases in chlorophyll concentrations.

Overall, chlorophyll concentrations were relatively low during the second half of 2001, but reached atypically high levels during the late fall/winter bloom in early December. Fall 2001 was a departure from the trend observed during the two previous years. During September and October of 1999 and

2000, substantial and prolonged fall blooms were observed, but in 2001 there was a minor fall bloom in September and then a more prolonged and substantial bloom was observed from late October thru early December. SeaWiFS imagery confirmed that elevated surface concentrations of chlorophyll were present from October to early December in the bays and throughout the western Gulf of Maine. The high chlorophyll concentrations in early December were coincident with high POC concentrations and seasonal peak areal production rates (>3250 mg C $m^{-2}$ $d^{-1}$). This was relatively late for the peak production rates and chlorophyll concentrations to be observed. These were the highest December values observed since baseline monitoring began in 1992.

Total phytoplankton abundances in the whole water samples were highest in late July and generally decreased through December. The decrease in phytoplankton abundance from fall to early winter is typical for this time of year. However, in comparison to previous years the late fall and early winter abundance levels were relatively high. Levels of $>10^6$ cells $L^{-1}$ in the nearfield (mostly centric diatoms) from October to early December were coincident with high chlorophyll concentrations and primary production rates. Zooplankton abundance and community structure followed typical patterns for the summer to early winter period.

September 6, 2000 marked the end of the baseline period, completing the data set for MWRA to calculate the threshold values used to compare monitoring results to baseline conditions. The water quality parameters included as thresholds are annual and seasonal chlorophyll levels in the nearfield, dissolved oxygen concentrations and percent saturation in bottom waters of the nearfield and Stellwagen Basin, and nuisance algae (*Alexandrium*, *Phaeocystis*, and *Pseudo-nitzschia*). Even with elevated chlorophyll concentrations from late October to early December the fall nearfield mean areal chlorophyll value was about half (85 mg $m^{-2}$) that of the fall threshold value (161 mg $m^{-2}$). This continued a trend of relatively low chlorophyll concentrations that had been noted for the first half of 2001. The low concentrations from February to December resulted in summer and annual mean areal chlorophyll values (45 and 67 mg $m^{-2}$) that were also well below threshold levels (80 and 107 mg $m^{-2}$). The DO concentration and percent saturation survey mean minima for the fall of 2001 were well above the threshold levels for both the nearfield and Stellwagen Basin. Although *Alexandrium* and *Pseudo-nitzschia* were observed intermittently and at very low abundance, there were no confirmed blooms of harmful or nuisance algae in Massachusetts and Cape Cod Bays for July – December 2001.

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# 1.0 INTRODUCTION

## *1.1 Program Overview*

The Massachusetts Water Resources Authority (MWRA) has implemented a long-term Harbor and Outfall Monitoring (HOM) Program for Massachusetts and Cape Cod Bays. The objective of the HOM Program is to (1) test for compliance with NPDES permit requirements; (2) test whether the impact of the discharge on the environment is within the bounds projected by the SEIS; and (3) test whether change within the system exceeds the Contingency Plan thresholds. A detailed description of the monitoring and its rationale is provided in the Effluent Outfall Monitoring Plan developed for the baseline period and the post discharge monitoring plan (MWRA, 1997).

To monitor water quality conditions with respect to nutrients, water properties, phytoplankton and zooplankton, and water-column respiration and productivity, the MWRA conducts ambient water quality surveys in Massachusetts and Cape Cod Bays. The surveys have been designed to evaluate water quality on both a high-frequency basis for a limited area (nearfield) and a low-frequency basis for an extended area (farfield). The nearfield stations are located in the vicinity of the Massachusetts Bay outfall site (Figure 1-1) and the farfield stations are located throughout Boston Harbor, Massachusetts Bay, and Cape Cod Bay (Figure 1-2). The stations for the farfield surveys have been further separated into regional groupings according to geographic location to simplify regional data comparisons. This semiannual report summarizes water column monitoring results for the ten surveys conducted from July through December 2001 (Table 1-1).

**Table 1-1. Water Quality Surveys for WF018-WN01H July to December 2001**

| Survey # | Type of Survey | Survey Dates |
|---|---|---|
| WN018 | Nearfield | July 12 |
| WN019 | Nearfield | July 25 |
| WN01A | Nearfield | August 9 |
| WF01B | Nearfield/Farfield | August 27-30 |
| WN01C | Nearfield | September 17 |
| WN01D | Nearfield | October 9 |
| WF01E | Nearfield/Farfield | October 19-22, 25-27 |
| WN01F | Nearfield | October 29 |
| WN01G | Nearfield | December 7 |
| WN01H | Nearfield | December 19 |

The bay outfall became operational on September 6, 2000. The ten surveys conducted during this semiannual period are the first summer surveys and second fall-winter surveys conducted after discharge of secondary treated effluent from the outfall began. The data evaluated and discussed in this report focus on characterization of spatial and temporal trends for July to December 2001. Preliminary comparison against baseline data are discussed and appropriate threshold values presented. A detailed evaluation of 2001 versus the baseline period (1992-2000) will be presented in the 2001 annual water column report.

Initial data summaries, along with specific field information, are available in individual survey reports submitted immediately following each survey. In addition, nutrient data reports (including calibration information, sensor and water chemistry data), plankton data reports, and productivity and respiration data reports are each submitted four times annually. Raw data summarized within this or any of the other reports are available from MWRA in hard copy and electronic formats.

## 1.2 Organization of the Semiannual Report

The scope of the semiannual report is focused primarily towards providing an initial compilation of the water column data collected during the reporting period. Secondarily, integrated physical and biological results are discussed for key water column events and potential areas for expanded discussion in the annual water column report are recommended. The report first provides a summary of the survey and laboratory methods (Section 2). The bulk of the report, as discussed in further detail below, presents results of water column data from the last ten surveys of 2001 (Sections 3-5). Finally, the major findings of the semiannual period are summarized in Section 6.

Section 3 includes data summary tables that present the major numeric results of water column surveys in the semiannual period by survey. A description of data selection, integration information, and summary statistics are included with that section.

Sections 4 (Results of Water Column Measurements) and 5 (Productivity, Respiration, and Plankton Results) include preliminary interpretation of the data with selected graphic representations of the horizontal and vertical distribution of water column parameters in both the farfield and nearfield. The horizontal distribution of physical parameters is presented through regional contour plots. The vertical distribution of water column parameters is presented using time-series plots of averaged surface and bottom water column parameters and along vertical transects in the survey area (Figure 1-3). The time-series plots utilize average values of the surface water sample (the "A" depth, as described in Section 3), and the bottom water collection depth (the "E" depth). Examining data trends along four farfield transects (Boston-Nearfield, Cohasset, Marshfield and Nearfield-Marshfield), and one nearfield transect, allows three-dimensional presentation of water column conditions during each survey. One offshore transect (Boundary) enables analysis of results in the outer most boundary of the survey area during farfield surveys.

Results of water column physical, nutrient, chlorophyll, and dissolved oxygen data are provided in Section 4. Survey results were organized according to the physical characteristics of the water column during the semiannual period. The timing of water column vertical stratification, and the physical and biological status of the water column during stratification, significantly affects the temporal response of the water quality parameters, which provide a major focus for assessing effects of the outfall. This report describes the horizontal and vertical characterization of the water column during the summer stratification period (WN018 – WF01E), the prolonged duration of weakly stratified conditions (WN01F – WN01G), and the eventual return to winter conditions in late December (WN01H). Time-series data are commonly provided for the entire semiannual period for clarity and context of the data presentation.

Productivity, respiration, and plankton measurements, along with corresponding discussion of chlorophyll and dissolved oxygen results, are provided in Section 5. Discussion of the biological processes and trends during the semiannual period is included in this section. A summary of the major water column events and unusual features of the semiannual period is presented in Section 6. References are provided in Section 7.

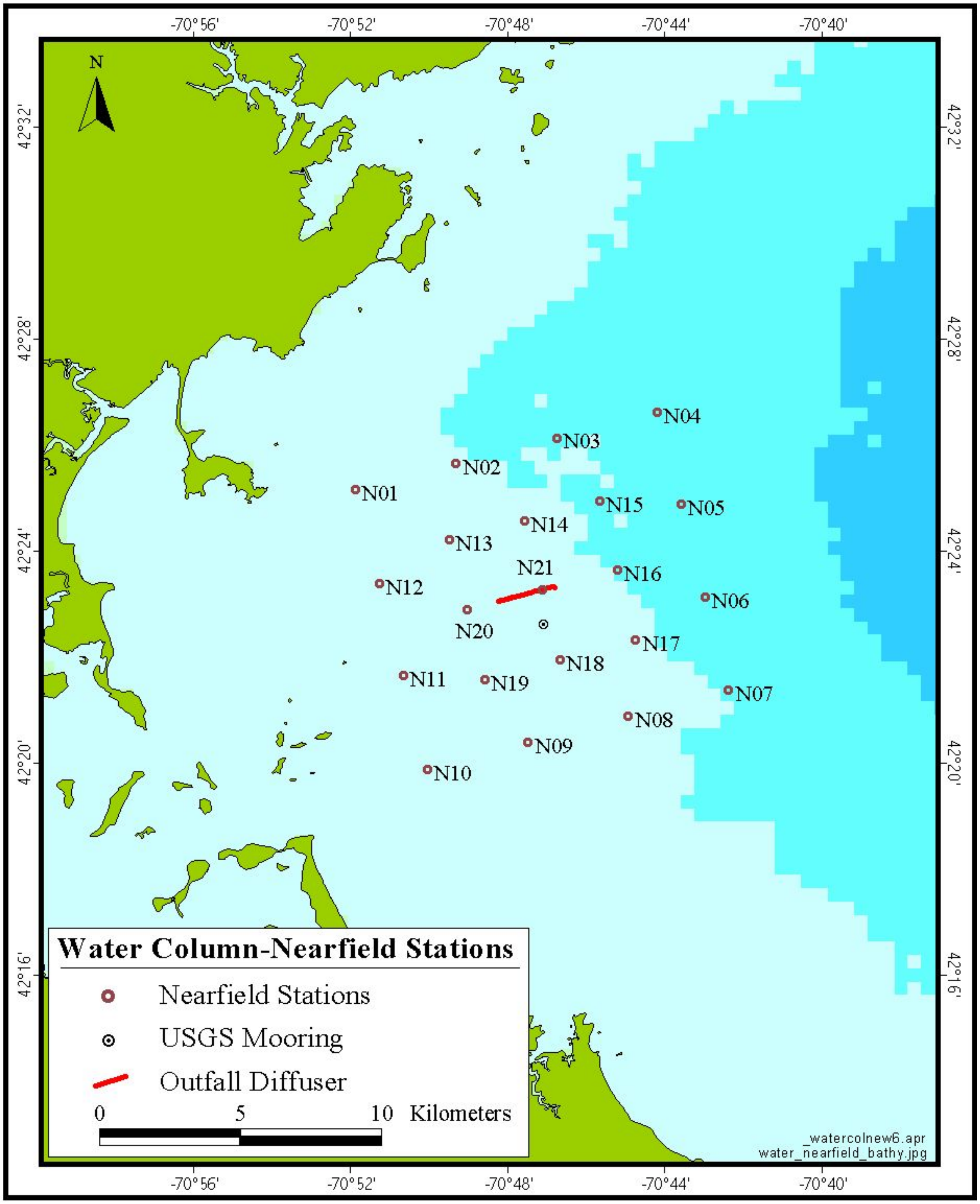



**Figure 1-1. Locations of MWRA Offshore Outfall, Nearfield Stations and USGS Mooring**

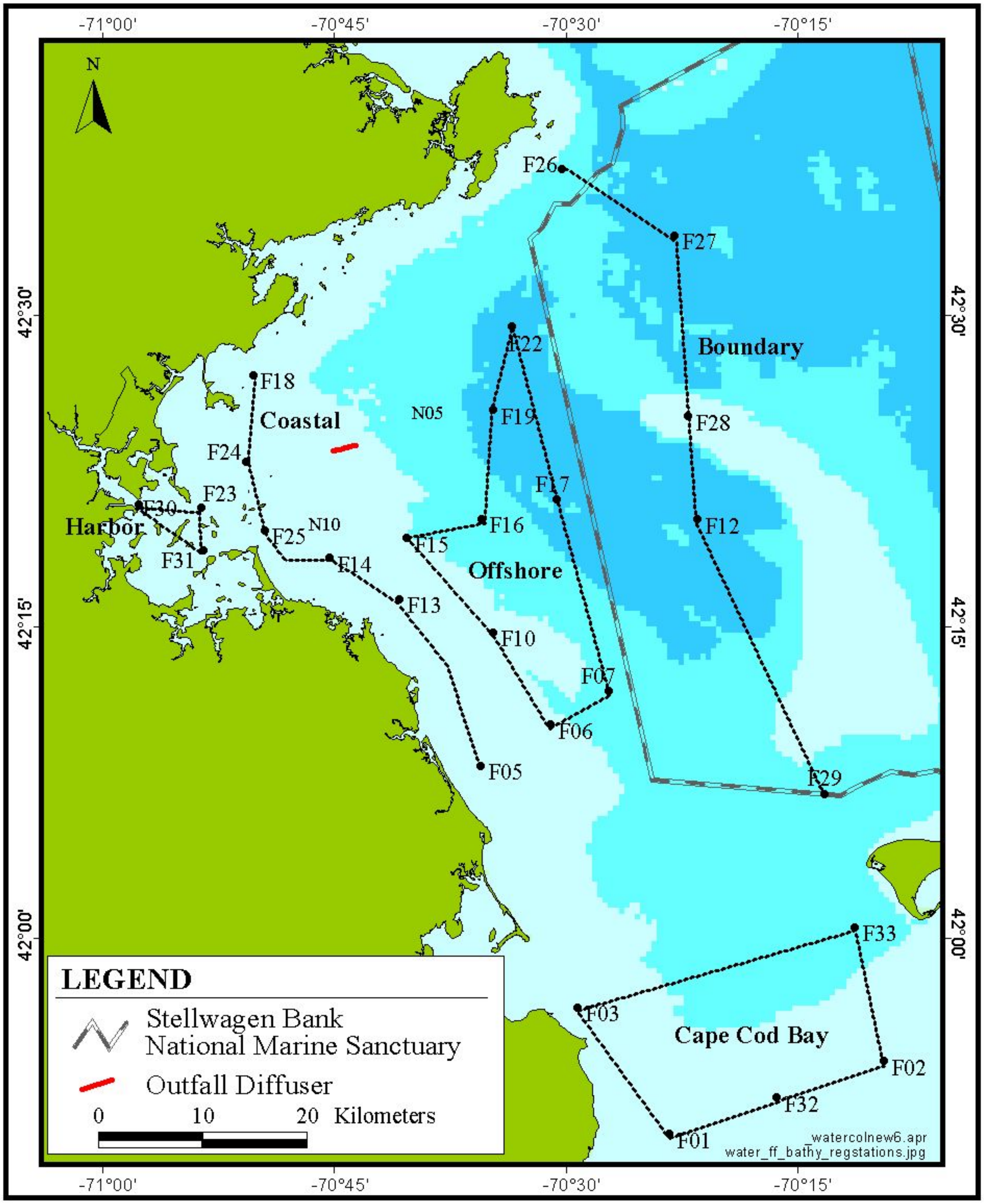



**Figure 1-2. Locations of Farfield Stations and Regional Station Groupings**

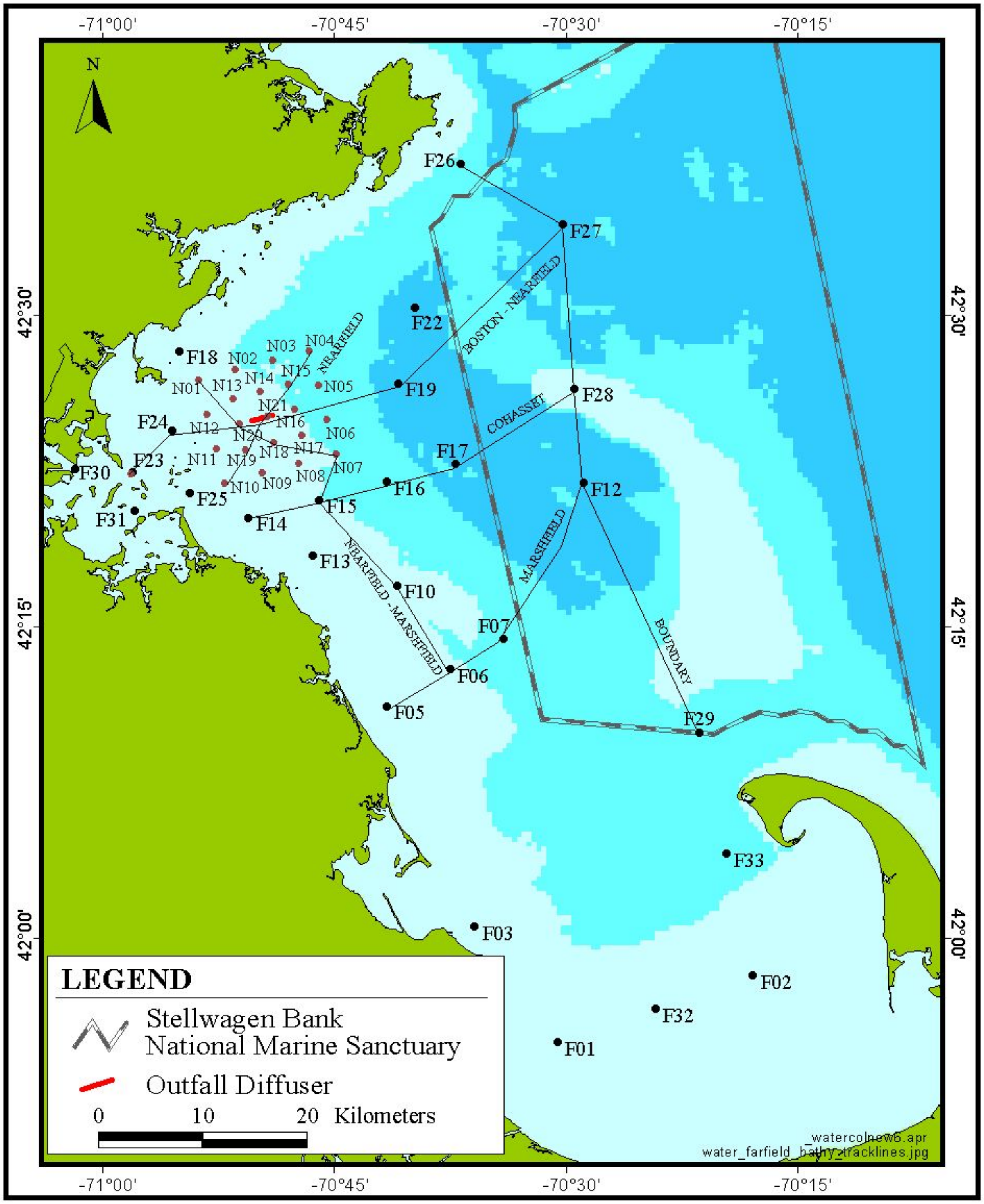



**Figure 1-3. Locations of Stations and Selected Transects**

# 2.0 METHODS

This section describes general methods of data collection and sampling for the last ten water column monitoring surveys of 2001. Section 2.1 describes data collection methods, including survey dates, sampling platforms, and analyses performed. Section 2.2 describes the sampling schema undertaken, and Section 2.3 details specific operations for the last 2001 semi-annual period. Specific details of field sampling and analytical procedures, laboratory sample processing and analysis, sample handling and custody, calibration and preventative maintenance, documentation, data evaluation, and data quality procedures are discussed in the Water Quality Monitoring CW/QAPP (Albro *et al.,* 2002). Details on productivity sampling procedures and analytical methods are also available in Appendix A.

## 2.1 Data Collection

The farfield and nearfield water quality surveys for 2001 represent a continuation of the water quality monitoring conducted from 1992 - 2000. On September 6, 2000, the offshore outfall went online and began discharging effluent. The baseline monitoring period includes surveys from February 1992 to September 1, 2000. The last 5 fall 2000 surveys represented the beginning of the outfall discharge monitoring period, which continued in 2001. The data collected during outfall discharge monitoring are evaluated internally and against baseline data. Data collection methods and schema have not changed from the baseline to the outfall discharge water quality monitoring periods.

Water quality data for this report were collected from the sampling platforms *R/V Aquamonitor* and *F/V Andrea J.* Continuous vertical profiles of the water column and discrete water samples were collected using a CTD/Go-Flo Bottle Rosette system. This system includes a deck unit to control the system, display *in situ* data, and store the data, and an underwater unit comprised of several environmental sensors, including conductivity, temperature, depth, dissolved oxygen, transmissometry, irradiance, and fluorescence. These measurements were obtained at each station by deploying the CTD; in general, one cast was made at each station. Water column profile data were collected during the downcast, and water samples were collected during the upcast by closing the Go-Flo bottles at selected depths, as discussed below.

Water samples were collected at five depths at each station, except at stations F30, F31, F32, and F33. Stations F30 and F31 are shallow and require only three depths while only zooplankton samples are collected at F32 and F33 (winter/spring surveys only). These depths were selected during CTD deployment based on positions relative to the pycnocline or subsurface chlorophyll maximum. The bottom depth (within 5 meters of the sea floor) and the surface depth (within 3 meters of the water surface) of each cast remained constant and the mid-bottom, middle and mid-surface depths were selected to represent any variability in the water column. In general, the selected middle depth corresponded with the chlorophyll maximum or pycnocline. When the chlorophyll maximum occurred significantly below or above the middle depth, the mid-bottom or mid-surface sampling event was substituted with the mid-depth sampling event and the "mid-depth" sample was collected within the maximum. In essence, the "mid-depth" sample in these instances was not collected from the middle depth, but shallower or deeper in the water column to capture the chlorophyll maximum layer. These nomenclature semantics result from a combination of field logistics and scientific relevance. In the field, the switching of the "mid-depth" sample with the mid-surface or mid-bottom was transparent to everyone except the NAVSAM operator who observed the subsurface chlorophyll structure and marked the events. The samples were processed in a consistent manner and a more comprehensive set of analyses was conducted for the surface, mid-depth/chlorophyll maximum, and bottom samples.

Samples from each depth at each station were collected by subsampling from the Go-Flo bottles into the appropriate sample container. Analyses performed on the water samples are summarized in Table 2-1. Samples for dissolved inorganic nutrients (DIN), dissolved organic carbon (DOC), total dissolved nitrogen (TDN) and phosphorus (TDP), particulate organic carbon (POC) and nitrogen (PON), biogenic silica, particulate phosphorus (PP), chlorophyll *a* and phaeopigments, total suspended solids (TSS), urea, and phytoplankton (screened and rapid assessment) were filtered and preserved immediately after obtaining water from the appropriate Go-Flo bottles. Whole water phytoplankton samples (unfiltered) were obtained directly from the Go-Flo bottles and immediately preserved. Zooplankton samples were obtained by deploying a zooplankton net overboard and making an oblique tow of the upper two-thirds of the water column but with a maximum tow depth of 30 meters. Productivity samples were collected from the Go-Flo bottles, stored on ice and transferred to University of Rhode Island (URI) employees. Incubation was started no more that six hours after initial water collection at URI's laboratory. Respiration samples were collected from the Go-Flo bottles at four stations (F19, F23, N04, and N18). Incubations of the dark bottles were started within 30 minutes of sample collection. The dark bottle samples were maintained at a temperature within 2°C of the collection temperature for five to seven days until analysis.

## 2.2 Sampling Schema

A synopsis of the sampling schema for the analyses described above is outlined in Tables 2-1, 2-2, and 2-3. Station designations were assigned according to the type of analyses performed at that station (see Table 2-1). Productivity and respiration analyses were also conducted at certain stations and represented by the letters P and R, respectively. Table 2-1 lists the different analyses performed at each station. Tables 2-2 (nearfield stations) and 2-3 (farfield stations) provide the station name and type, and show the analyses performed at each depth. Station N16 is considered both a nearfield station (where it is designated as type A) and a farfield station (where it is designated a type D). Stations F32 and F33 are occupied during the first three farfield surveys of each year and collect zooplankton samples and hydrocast data only (designated as type Z).

**Table 2-1. Station Types and Numbers (Five Depths Collected Unless Otherwise Noted)**

| Station Type | A | D | E | F | G[1] | P | R[4] | Z |
|---|---|---|---|---|---|---|---|---|
| Number of Stations | 6 | 10 | 24 | 2 | 2 | 3 | 1 | 2 |
| Analysis Type | | | | | | | | |
| Dissolved inorganic nutrients ($NH_4$, $NO_3$, $NO_2$, $PO_4$, and $SiO_4$) | ● | ● | ● | ● | ● | ● | | |
| Other nutrients (DOC, TDN, TDP, PC, PN, PP, Biogenic Si)[1] | ● | ● | | | ● | ● | | |
| Chlorophyll [1] | ● | ● | | | ● | ● | | |
| Total suspended solids [1] | ● | ● | | | ● | ● | | |
| Dissolved oxygen | ● | ● | | ● | ● | ● | | |
| Phytoplankton, urea [2] | | ● | | | ● | ● | | |
| Zooplankton[3] | | ● | | | ● | ● | | ● |
| Respiration [1] | | | | | | ● | ● | |
| Productivity, DIC | | | | | | ● | | |

[1]Samples collected at three depths (bottom, mid-depth, and surface)
[2]Samples collected at two depths (mid-depth and surface)
[3]Vertical tow samples collected
[4]Respiration samples collected at type A station F19

### 2.3 Operations Summary

Field operations for water column sampling and analysis during the last 2001 semi-annual period were conducted as described above. Deviations from the CW/QAPP for surveys WN018, WN019, WN01D, WF01E, WN01F, WN01G and WN01H had no effect on the data or data interpretation. During survey WN01C, instrument problems were noted with the DO sensor. The instrumentation problem was corrected in the field for WN01C, but when investigated it was determined that all of the *in situ* DO data from WN01A and WF01B were suspect. For additional information about a specific survey, the individual survey reports may be consulted.

**Table 2-2. Nearfield Water Column Sampling Plan (3 Pages)**

## Nearfield Water Column Sampling Plan

| StationID | Depth (m) | Station Type | Depths | Total Volume at Depth (L) | Number of 9-L GoFlos | Dissolved Inorganic Nutrients | Dissolved Organic Carbon | Total Dissolved Nitrogen and Phosphorous | Particulate Organic Carbon and Nitrogen | Particulate Phosphorous | Biogenic silica | Chlorophyll a | Total Suspended Solids | Dissolved Oxygen | Rapid Analysis Phytoplankton | Whole Water Phytoplankton | Screened Water Phytoplankton | Zooplankton | Urea | Respiration | Photosynthesis by carbon-14 | Dissolved Inorganic Carbon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Protocol Code | | | IN | OC | NP | PC | PP | BS | CH | TS | DO | RP | WW | SW | ZO | UR | RE | AP | IC |
| | | | Volume (L) | | | 1 | 0.1 | 0.1 | 1 | 0.6 | 0.3 | 0.5 | 1 | 1 | 4 | 1 | 4 | 1 | 0.1 | 1 | 1 | 1 |
| | | | 1_Bottom | 8.5 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | | | | | | | | |
| | | | 2_Mid-Bottom | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| N01 | 30 | A | 3_Mid-Depth | 10 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | | | | | | | | |
| | | | 4_Mid-Surface | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| | | | 5_Surface | 8.5 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | | | | | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| N02 | 40 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| N03 | 44 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 1_Bottom | 15.5 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | | | | | | | 6 | 1 | 1 |
| | | | 2_Mid-Bottom | 4.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | 1 | 1 |
| N04 | 50 | D+ | 3_Mid-Depth | 22.1 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | | | 1 | 1 | | 1 | 6 | 1 | 1 |
| | | R+ | 4_Mid-Surface | 4.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | 1 | 1 |
| | | P | 5_Surface | 20.6 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | | | 1 | 1 | | 1 | 6 | 1 | 1 |
| | | | 6_Net Tow | | | | | | | | | | | | | | | 1 | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| N05 | 55 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| N06 | 52 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 1_Bottom | 10.5 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 3 | | | | | | | | |
| | | | 2_Mid-Bottom | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| N07 | 52 | A | 3_Mid-Depth | 10 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | | | | | | | | |
| | | | 4_Mid-Surface | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| | | | 5_Surface | 10.5 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 3 | | | | | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| N08 | 35 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |

## Nearfield Water Column Sampling Plan

| StationID | Depth (m) | Station Type | Depths | Total Volume at Depth (L) | Number of 9-L GoFlos | Dissolved Inorganic Nutrients | Dissolved Organic Carbon | Total Dissolved Nitrogen and Phosphorous | Particulate Organic Carbon and Nitrogen | Particulate Phosphorous | Biogenic silica | Chlorophyll a | Total Suspended Solids | Dissolved Oxygen | Rapid Analysis Phytoplankton | Whole Water Phytoplankton | Screened Water Phytoplankton | Zooplankton | Urea | Respiration | Photosynthesis by carbon-14 | Dissolved Inorganic Carbon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Protocol Code | | | IN | OC | NP | PC | PP | BS | CH | TS | DO | RP | WW | SW | ZO | UR | RE | AP | IC |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| N09 | 32 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 1_Bottom | 8.5 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | | | | | | | | |
| | | | 2_Mid-Bottom | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| N10 | 25 | A | 3_Mid-Depth | 10 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | | | | | | | | |
| | | | 4_Mid-Surface | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| | | | 5_Surface | 8.5 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | | | | | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| N11 | 32 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| N12 | 26 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| N13 | 32 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| N14 | 34 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| N15 | 42 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 1_Bottom | 8.5 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | | | | | | | | |
| | | | 2_Mid-Bottom | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| N16 | 40 | A | 3_Mid-Depth | 10.2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | | | | | | | | |
| | | | 4_Mid-Surface | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| | | | 5_Surface | 8.5 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | | | | | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| N17 | 36 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |

# Nearfield Water Column Sampling Plan

| StationID | Depth (m) | Station Type | Depths | Total Volume at Depth (L) | Number of 9-L GoFlos | Dissolved Inorganic Nutrients | Dissolved Organic Carbon | Total Dissolved Nitrogen and Phosphorous | Particulate Organic Carbon and Nitrogen | Particulate Phosphorous | Biogenic silica | Chlorophyll a | Total Suspended Solids | Dissolved Oxygen | Rapid Analysis Phytoplankton | Whole Water Phytoplankton | Screened Water Phytoplankton | Zooplankton | Urea | Respiration | Photosynthesis by carbon-14 | Dissolved Inorganic Carbon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Protocol Code | | | IN | OC | NP | PC | PP | BS | CH | TS | DO | RP | WW | SW | ZO | UR | RE | AP | IC |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 1_Bottom | 15.5 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | | | | | | | 6 | 1 | 1 |
| | | D+ | 2_Mid-Bottom | 4.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | 1 | 1 |
| N18 | 30 | R+ | 3_Mid-Depth | 26.1 | 3 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | | 1 | 1 | 1 | | 1 | 6 | 1 | 2 |
| | | P | 4_Mid-Surface | 4.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | 1 | 1 |
| | | | 5_Surface | 20.6 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | | | 1 | 1 | | 1 | 6 | 1 | 1 |
| | | | 6_Net Tow | | | | | | | | | | | | | | | 1 | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| N19 | 24 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 1_Bottom | 8.5 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | | | | | | | | |
| | | | 2_Mid-Bottom | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| N20 | 32 | A | 3_Mid-Depth | 10 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | | | | | | | | |
| | | | 4_Mid-Surface | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| | | | 5_Surface | 8.5 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | | | | | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| N21 | 34 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | | Totals | | 111 | 22 | 22 | 42 | 42 | 42 | 42 | 42 | 33 | 1 | 4 | 4 | 2 | 4 | 36 | 10 | 11 |
| Blanks A | | | | | | | | | 1 | 1 | 1 | 1 | 1 | | | | | | | | | |

**Table 2-3. Farfield Water Column Sampling Plan (3 Pages)**

## Farfield Water Column Sampling Plan

| StationID | Depth (m) | Station Type | Depths | Total Volume at Depth (L) | Number of 9-L GoFlos | Dissolved Inorganic Nutrients | Dissolved Organic Carbon | Total Dissolved Nitrogen and | Particulate Organic Carbon | Particulate Phosphorous | Biogenic silica | Chlorophyll a | Total Suspended Solids | Dissolved Oxygen | Secchi Disk Reading | Whole Water Phytoplankton | Screened Water Phytoplankton | Zooplankton | Urea | Respiration | Photosynthesis by carbon-14 | Dissolved Inorganic Carbon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Protocol Code | | | IN | OC | NP | PC | PP | BS | CH | TS | DO | SE | WW | SW | ZO | UR | RE | AP | IC |
| | | | Volume (L) | | | 1 | 0.1 | 0.1 | 1 | 0.3 | 0.3 | 0.5 | 1 | 1 | 0 | 1 | 4 | 1 | 0.1 | 1 | 1 | 1 |
| | | | 1_Bottom | 7.9 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 3 | | | | | | | | |
| | | | 2_Mid-Bottom | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| F01 | 27 | D | 3_Mid-Depth | 14 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | | 1 | 1 | | 1 | | | |
| | | | 4_Mid-Surface | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| | | | 5_Surface | 13 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 3 | 1 | 1 | 1 | | 1 | | | |
| | | | 6_Net Tow | | | | | | | | | | | | | | | 1 | | | | |
| | | | 1_Bottom | 7.9 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | | | | | | | | |
| | | | 2_Mid-Bottom | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| F02 | 33 | D | 3_Mid-Depth | 15 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | | 1 | 1 | | 1 | | | |
| | | | 4_Mid-Surface | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| | | | 5_Surface | 13 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | | 1 | | | |
| | | | 6_Net Tow | | | | | | | | | | | | | | | 1 | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| F03 | 17 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | 1 | | | | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| F05 | 18 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | 1 | | | | | | | |
| | | | 1_Bottom | 7.9 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 3 | | | | | | | | |
| | | | 2_Mid-Bottom | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| F06 | 35 | D | 3_Mid-Depth | 15 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | | 1 | 1 | | 1 | | | |
| | | | 4_Mid-Surface | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| | | | 5_Surface | 13 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 3 | 1 | 1 | 1 | | 1 | | | |
| | | | 6_Net Tow | | | | | | | | | | | | | | | 1 | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| F07 | 54 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | 1 | | | | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| F10 | 30 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | 1 | | | | | | | |
| | | | 1_Bottom | 4 | 1 | 1 | | | | | | | | 1 | | | | | | | | |
| | | | 2_Mid-Bottom | 2 | 1 | 1 | | | | | | | | 1 | | | | | | | | |
| F12 | 90 | F | 3_Mid-Depth | 2 | 1 | 1 | | | | | | | | 1 | | | | | | | | |
| | | | 4_Mid-Surface | 2 | 1 | 1 | | | | | | | | 1 | | | | | | | | |
| | | | 5_Surface | 4 | 1 | 1 | | | | | | | | 1 | 1 | | | | | | | |
| | | | 1_Bottom | 7.9 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | | | | | | | | |
| | | | 2_Mid-Bottom | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| F13 | 25 | D | 3_Mid-Depth | 15 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | | 1 | 1 | | 1 | | | |
| | | | 4_Mid-Surface | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |

# Farfield Water Column Sampling Plan

| StationID | Depth (m) | Station Type | Depths | Total Volume at Depth (L) | Number of 9-L GoFlos | Dissolved Inorganic Nutrients | Dissolved Organic Carbon | Total Dissolved Nitrogen and Phosphorus | Particulate Organic Carbon | Particulate Phosphorous | Biogenic silica | Chlorophyll a | Total Suspended Solids | Dissolved Oxygen | Secchi Disk Reading | Whole Water Phytoplankton | Screened Water Phytoplankton | Zooplankton | Urea | Respiration | Photosynthesis by carbon-14 | Dissolved Inorganic Carbon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Protocol Code | | | IN | OC | NP | PC | PP | BS | CH | TS | DO | SE | WW | SW | ZO | UR | RE | AP | IC |
| | | | 5_Surface | 13 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | | 1 | | | |
| | | | 6_Net Tow | | | | | | | | | | | | | | | 1 | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| F14 | 20 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | 1 | | | | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| F15 | 39 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | 1 | | | | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| F16 | 60 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | 1 | | | | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| F17 | 78 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | 1 | | | | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| F18 | 24 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | 1 | | | | | | | |
| | | | 1_Bottom | 7 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | | | | | | | 6 | | |
| | | | 2_Mid-Bottom | 2 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| F19 | 81 | A | 3_Mid-Depth | 7 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | | | | | | | 6 | | |
| | | +R | 4_Mid-Surface | 2 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| | | | 5_Surface | 7 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | | 1 | | | | | 6 | | |
| | | | 1_Bottom | 7.9 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 3 | | | | | | | | |
| | | | 2_Mid-Bottom | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| F22 | 80 | D | 3_Mid-Depth | 14 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | | 1 | 1 | | 1 | | | |
| | | | 4_Mid-Surface | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| | | | 5_Surface | 13 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 3 | 1 | 1 | 1 | | 1 | | | |
| | | | 6_Net Tow | | | | | | | | | | | | | | | 1 | | | | |
| | | | 1_Bottom | 18 | 3 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | | | | | | | 6 | 1 | 1 |
| | | D | 2_Mid-Bottom | 8.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | 1 | 2 |
| F23 | 25 | +R | 3_Mid-Depth | 24 | 3 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | | | 1 | 1 | | 1 | 6 | 1 | 1 |
| | | +P | 4_Mid-Surface | 7.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | 1 | 1 |
| | | | 5_Surface | 23 | 3 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | | 1 | 1 | 1 | | 1 | 6 | 1 | 1 |
| | | | 6_Net Tow | | | | | | | | | | | | | | | 1 | | | | |
| | | | 1_Bottom | 7.9 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 3 | | | | | | | | |
| | | | 2_Mid-Bottom | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| F24 | 20 | D | 3_Mid-Depth | 14 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | | 1 | 1 | | 1 | | | |
| | | | 4_Mid-Surface | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| | | | 5_Surface | 13 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 3 | 1 | 1 | 1 | | 1 | | | |
| | | | 6_Net Tow | | | | | | | | | | | | | | | 1 | | | | |
| | | | 1_Bottom | 9.9 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | | | | | | | | |
| | | | 2_Mid-Bottom | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |

# Farfield Water Column Sampling Plan

| StationID | Depth (m) | Station Type | Depths | Total Volume at Depth (L) | Number of 9-L GoFlos | Dissolved Inorganic Nutrients | Dissolved Organic Carbon | Total Dissolved Nitrogen and | Particulate Organic Carbon | Particulate Phosphorous | Biogenic silica | Chlorophyll a | Total Suspended Solids | Dissolved Oxygen | Secchi Disk Reading | Whole Water Phytoplankton | Screened Water Phytoplankton | Zooplankton | Urea | Respiration | Photosynthesis by carbon-14 | Dissolved Inorganic Carbon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Protocol Code | | IN | OC | NP | PC | PP | BS | CH | TS | DO | SE | WW | SW | ZO | UR | RE | AP | IC |
| F25 | 15 | D | 3_Mid-Depth | 15 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | | 1 | 1 | | 1 | | | |
| | | | 4_Mid-Surface | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| | | | 5_Surface | 15 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 3 | 1 | 1 | 1 | | 1 | | | |
| | | | 6_Net Tow | | | | | | | | | | | | | | | 1 | | | | |
| | | | 1_Bottom | 7.9 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | | | | | | | | |
| | | | 2_Mid-Bottom | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| F26 | 56 | D | 3_Mid-Depth | 15 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | | 1 | 1 | | 1 | | | |
| | | | 4_Mid-Surface | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| | | | 5_Surface | 13 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | | 1 | | | |
| | | | 6_Net Tow | | | | | | | | | | | | | | | 1 | | | | |
| | | | 1_Bottom | 7.9 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | | | | | | | | |
| | | | 2_Mid-Bottom | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| F27 | 108 | D | 3_Mid-Depth | 15 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | | 1 | 1 | | 1 | | | |
| | | | 4_Mid-Surface | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| | | | 5_Surface | 13 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | | 1 | | | |
| | | | 6_Net Tow | | | | | | | | | | | | | | | 1 | | | | |
| | | | 1_Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 2_Mid-Bottom | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| F28 | 33 | E | 3_Mid-Depth | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 4_Mid-Surface | 1 | 1 | 1 | | | | | | | | | | | | | | | | |
| | | | 5_Surface | 1 | 1 | 1 | | | | | | | | | 1 | | | | | | | |
| | | | 1_Bottom | 2 | 1 | 1 | | | | | | | | 1 | | | | | | | | |
| | | | 2_Mid-Bottom | 2 | 1 | 1 | | | | | | | | 1 | | | | | | | | |
| F29 | 66 | F | 3_Mid-Depth | 2 | 1 | 1 | | | | | | | | 1 | | | | | | | | |
| | | | 4_Mid-Surface | 2 | 1 | 1 | | | | | | | | 1 | | | | | | | | |
| | | | 5_Surface | 2 | 1 | 1 | | | | | | | | 1 | 1 | | | | | | | |
| | | | 1_Bottom | 9.9 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 3 | | | | | | | | |
| | | | 3_Mid-Depth | 14 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | | 1 | 1 | | 1 | | | |
| F30 | 15 | G | 5_Surface | 15 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 3 | 1 | 1 | 1 | | 1 | | | |
| | | | 6_Net Tow | | | | | | | | | | | | | | | 1 | | | | |
| | | | 1_Bottom | 9.9 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 3 | | | | | | | | |
| | | | 3_Mid-Depth | 14 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | | 1 | 1 | | 1 | | | |
| F31 | 15 | G | 5_Surface | 15 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 3 | 1 | 1 | 1 | | 1 | | | |
| | | | 6_Net Tow | | | | | | | | | | | | | | | 1 | | | | |
| F32 | 30 | Z | 5_Surface | | | | | | | | | | | | 1 | | | | | | | |
| | | | 6_Net Tow | | | | | | | | | | | | | | | 1 | | | | |
| F33 | 30 | Z | 5_Surface | | | | | | | | | | | | 1 | | | | | | | |
| | | | 6_Net Tow | | | | | | | | | | | | | | | 1 | | | | |
| | | | 1_Bottom | 8.1 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 1 | | | | | | | | |
| | | | 2_Mid-Bottom | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| N16 | 40 | D | 3_Mid-Depth | 15 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | | 1 | 1 | | 1 | | | |
| | | | 4_Mid-Surface | 2.5 | 1 | 1 | | | | | | 1 | | 1 | | | | | | | | |
| | | | 5_Surface | 13 | 2 | 1 | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | | 1 | | | |
| | | | 6_Net Tow | | | | | | | | | | | | | | | 1 | | | | |
| | | | | | otals | 132 | 44 | 44 | 84 | 84 | 84 | 80 | 84 | 96 | 28 | 26 | 26 | 15 | 26 | 36 | 5 | 6 |
| | | | Blanks B | | | | | | 1 | 1 | 1 | 1 | 1 | | | | | | | | | |
| | | | Blanks C | | | | | | 1 | 1 | 1 | 1 | 1 | | | | | | | | | |
| | | | Blanks D | | | | | | 1 | 1 | 1 | 1 | 1 | | | | | | | | | |

# 3.0 DATA SUMMARY PRESENTATION

Data from each survey were compiled from the HOM Program 2001 database and organized to facilitate regional comparisons between surveys, and to allow a quick evaluation of results for evaluating monitoring thresholds (Table 3-1 Method Detection Limits and Survey Data Tables 3-2 through 3-11). Each table provides summary data from one survey. A discussion of which parameters were selected, how the data were grouped and integrated, and the assumptions behind the calculation of statistical values (average, minimum, and maximum) is provided below. Individual data summarized in this report are available from MWRA either in hard copy or electronic format.

The spatial pattern of data summary follows the sample design over major geographic areas of interest in Massachusetts Bay, Cape Cod Bay, and Boston Harbor (Section 3.1). Compilation of data both horizontally by region and vertically over the entire water column was conducted to provide an efficient way of assessing the status of the regions during a particular survey. Regional compilations of nutrient and biological water column data were conducted first by averaging individual laboratory replicates, followed by field duplicates, and then by station visit within a survey. Prior to regional compilation of the sensor data, the results were averaged by station visit. Significant figures for average values were selected based on precision of the specific data set. Detailed considerations for individual data sets are provided in the sections below.

## *3.1 Defined Geographic Areas*

The primary partitioning of data is between the nearfield and farfield stations (Figures 1-1 and 1-2). Farfield data were additionally segmented into five geographic areas: stations in Boston Harbor (F23, F30, and F31), coastal stations (F05, F13, F14, F18, F24, F25), offshore stations (F06, F07, F10, F15, F16, F17, F19, and F22), boundary region stations (F12, F26, F27, F28, F29), and Cape Cod Bay stations (F01, F02, and F03; and F32 and F33 as appropriate). These regions are shown in Figure 1-2.

The data summary tables include data derived from all of the station data collected in each region. Average, maximum, and minimum values are reported from the cumulative horizontal and vertical dataset as described for each data type below.

## *3.2 Sensor Data*

Six CTD profile parameters provided in the data summary tables include temperature, salinity, density ($\sigma_t$), fluorescence (chlorophyll a), transmissivity, and dissolved oxygen (DO) concentration. Statistical parameters (maximum, minimum, and average) were calculated from the sensor readings collected at five depths through the water column (defined as A-E). These depths were sampled on the upcast of the hydrographic profile. The five depth values, rather than the entire set of profile data, were selected to reduce the statistical weighting of deep-water data at the offshore and boundary stations. Generally, the samples were collected in an even depth-distributed pattern. The mid-depth sample (C) was typically located at the subsurface fluorescence (chlorophyll) peak in the water column, depending on the relative depth of the chlorophyll maximum. Details of the collection, calibration, and processing of CTD data are available in the Water Column Monitoring CW/QAPP (Albro *et al.,* 2002), and are summarized in Section 2.

Following standard oceanographic practice, patterns of variability in water density are described using the derived parameter sigma-*t* ($\sigma_{t,}$), which is calculated by subtracting 1,000 kg/m$^3$ from the recorded density. During this semi-annual period, density varied from 1021.8 to 1025.5, meaning $\sigma_t$ varied from 21.8 to 25.5.

Fluorescence data were calibrated using concomitant extracted chlorophyll *a* data from discrete water samples collected at a subset of the stations (see CW/QAPP or Tables 2-1, 2-2, 2-3). The calibrated fluorescence sensor values were used for all discussions of chlorophyll in this report. The concentrations of phaeopigments are included in the summary data tables as part of the nutrient parameters.

In addition to DO concentration, the derived percent saturation was also provided. Percent saturation was calculated prior to averaging station visits from the potential saturation value of the water (a function of the physical properties of the water) and the calibrated DO concentration (see CW/QAPP).

Finally, the derived beam attenuation coefficient from the transmissometer ("transmittance") was provided on the summary tables. Beam attenuation is calculated from the natural logarithm of the ratio of light transmission relative to the initial light incidence, over the transmissometer path length, and is provided in units of $m^{-1}$.

## 3.3 Nutrients

Analytical results for dissolved and particulate nutrient concentrations were extracted from the HOM database, and include: ammonia ($NH_4$), nitrite ($NO_2$), nitrate + nitrite ($NO_3$+$NO_2$), phosphate ($PO_4$), silicate ($SiO_4$), biogenic silica (BSI), dissolved and particulate organic carbon (DOC and POC), total dissolved and particulate organic nitrogen (TDN and PON), total dissolved and particulate phosphorous (TDP and PP), and urea. Total suspended solids (TSS) data are provided as a baseline for total particulate matter in the water column. Dissolved inorganic nutrients ($NH_4$, $NO_2$, $NO_3$+$NO_2$, $PO_4$, and $SiO_4$) were measured from water samples collected from each of the five (A-E) depths during CTD casts. The dissolved organic and particulate constituents were measured from water samples collected from the surface (A), mid-depth (C), and bottom (E) sampling depths (see Tables 2-1, 2-2, and 2-3 for specific sampling depths and stations).

## 3.4 Biological Water Column Parameters

Four productivity parameters have been presented in the data summary tables. Areal production, which is determined by integrating the measured productivity over the photic zone, and depth-averaged chlorophyll-specific production are included for the productivity stations (F23 representing the Harbor, and N04 and N18, representing the nearfield). Because areal production is already depth-integrated, averages were calculated only among productivity stations for the two regions sampled. The derived parameters $\alpha$ [$mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$] and Pmax ($mgCm^{-3}h^{-1}$) are also included. The productivity parameters are discussed in detail in Appendix A.

Respiration rates were averaged over the respiration stations [the same Harbor and nearfield stations as productivity, and additionally one offshore station (F19)], and over the three water column depths sampled (surface, mid-depth and bottom). The respiration samples were collected concurrently with the productivity samples except at Station F19. Detailed methods of sample collection, processing, and analysis are available in the CW/QAPP (Albro *et al.,* 2002).

## 3.5 Plankton

Plankton results were extracted from the HOM database and include whole water phytoplankton, screened phytoplankton, and zooplankton. Phytoplankton samples were collected for whole-water and screened measurements during the water column CTD casts at the surface (A) and mid-depth (C) sampling events. As discussed in Section 2.1, when a subsurface chlorophyll maximum is observed, the mid-depth sampling event is associated with this layer. The screened phytoplankton samples were filtered through 20-µm Nitrex mesh to retain and concentrate larger dinoflagellate species. Zooplankton samples were collected by oblique tows using a 102-µm mesh at all plankton stations. Detailed methods of sample collection, processing, and analysis are available in the CW/QAPP (Albro *et al.,* 2002).

Final plankton values were derived from each station by first averaging analytical replicates, and then averaging station visits. Regional results were summarized for total phytoplankton, total centric diatoms, nuisance algae (*Alexandrium tamarense, Phaeocystis pouchetii,* and *Pseudo-nitzschia pungens*), and total zooplankton (Tables 3-2 through 3-10).

Results for total phytoplankton and centric diatoms reported in Tables 3-2 through 3-10 are restricted to whole water surface samples. Results of the nuisance species *Phaeocystis pouchetii* and *Pseudo-nitzschia pungens* include the maximum of both whole water and screened analyses, at both the surface and mid-depth. Although the size and shape of both taxa might allow them to pass through the Nitex screen, both have colonial forms that in low densities might be overlooked in the whole-water samples. For *Alexandrium tamarense*, only the screened sample data were reported.

## 3.6 Additional Data

Two additional data sources were utilized during interpretation of HOM Program semi-annual water column data. Sea surface temperature and SeaWiFS chlorophyll *a* satellite images collected near survey dates were preliminarily interpreted for evidence of surface water events, including intrusions of surface water masses from the Gulf of Maine, upwelling, and regional blooms (Appendix I). U.S. Geological Service continuous temperature and salinity data were collected from a mooring located between nearfield stations N21 and N18 (Figure 1-1). Hourly temperature and salinity data from mid-surface (6 m), mid-depth (13 m), mid-bottom (20 m) and near-bottom (1 m above bottom, 27 m) are plotted in Figure 3-1. Chlorophyll *a* data (as measured by *in situ* fluorescence) from the MWRA WetStar sensor mounted at mid-depth (13 m below surface) on the nearfield USGS mooring are plotted in Figure 3-2. Data from stations N18 and N21 are included in both figures for comparison.

Due to instrument failure, data from the 1-meter above bottom (27 m) array are only available through July 24, 2001. Data from all instruments from October 23 to December 2001 are not yet available, but will be included in the 2001 annual water column report.

**Table 3-1. Method Detection Limits**

| Analysis | MDL |
|---|---|
| Dissolved ammonia ($NH_4$) | 0.02 µM |
| Dissolved inorganic nitrate ($NO_3$) | 0.01 µM |
| Dissolved inorganic nitrite ($NO_2$) | 0.01 µM |
| Dissolved inorganic phosphorus ($PO_4$) | 0.01 µM |
| Dissolved inorganic silicate ($SIO_4$) | 0.02 µM |
| Dissolved organic carbon (DOC) | 20 µM |
| Total dissolved nitrogen (TDN) | 1.43 µM |
| Total dissolved phosphorus (TDP) | 0.04 µM |
| Particulate carbon (POC) | 5.27 µM |
| Particulate nitrogen (PON) | 0.75 µM |
| Particulate phosphorus (PARTP) | 0.04 µM |
| Biogenic silica (BIOSI) | 0.32 µM |
| Urea | 0.2 µM |
| Chlorophyll *a* and phaeophytin | 0.036 µg $L^{-1}$ |
| Total suspended solids (TSS) | 0.1 mg $L^{-1}$ |

**Table 3-2. Nearfield Survey WN018 (Jul 01) Data Summary**

| Region | | Nearfield | | |
|---|---|---|---|---|
| **Parameter** | **Unit** | **Min** | **Max** | **Avg** |
| In Situ | | | | |
| Temperature | °C | 5.55 | 15.26 | 9.02 |
| Salinity | PSU | 30.6 | 31.7 | 31.3 |
| Sigma _T | | 22.7 | 25.0 | 24.2 |
| Beam Attenuation | $m^{-1}$ | 0.51 | 2.41 | 0.96 |
| DO Concentration | $mgL^{-1}$ | 9.03 | 11.63 | 9.95 |
| DO Saturation | PCT | 89.9 | 124.1 | 105.4 |
| Fluorescence | $\mu gL^{-1}$ | 0.02 | 11.56 | 1.73 |
| Chlorophyll a | $\mu gL^{-1}$ | 0.02 | 5.53 | 1.96 |
| Phaeopigment | $\mu gL^{-1}$ | 0.02 | 1.73 | 0.59 |
| Nutrients | | | | |
| NH4 | µM | 0.25 | 22.01 | 3.44 |
| NO2 | µM | 0.01 | 0.43 | 0.15 |
| NO2+NO3 | µM | 0.04 | 3.18 | 0.96 |
| PO4 | µM | 0.07 | 1.28 | 0.52 |
| SIO4 | µM | 0.54 | 8.27 | 3.26 |
| BIOSI | µM | 0.80 | 2.50 | 1.53 |
| DOC | µM | 159.4 | 401.9 | 233.6 |
| PARTP | µM | 0.06 | 0.42 | 0.27 |
| POC | µM | 7.14 | 61.5 | 32.08 |
| PON | µM | 1.31 | 7.50 | 4.42 |
| TDN | µM | 11.5 | 28.3 | 17.5 |
| TDP | µM | 0.39 | 1.18 | 0.65 |
| TSS | $mgL^{-1}$ | 0.38 | 1.50 | 0.83 |
| Urea | µM | 0.10 | 0.37 | 0.25 |
| Productivity | | | | |
| Alpha | $mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$ | 0.003 | 0.069 | 0.0432 |
| Pmax | $mgCm^{-3}h^{-1}$ | 0.43 | 11.00 | 4.64 |
| Areal Production | $mgCm^{-2}d^{-1}$ | 893.4 | 1,447.8 | 1,170.6 |
| Depth-averaged Chlorophyll-specific Production | $mgC(mg\ Chla)^{-1}d^{-1}$ | 11.9 | 27.7 | 19.8 |
| Respiration | $\mu MO_2h^{-1}$ | 0.021 | 0.224 | 0.132 |
| Plankton | | | | |
| Total Phytoplankton | $10^6$Cells $L^{-1}$ | 0.985 | 2.217 | 1.644 |
| Centric diatoms | $10^6$Cells $L^{-1}$ | 0.156 | 0.587 | 0.342 |
| *Alexandrium spp.* | Cells $L^{-1}$ | 2.6 | 2.6 | 2.6 |
| *Phaeocystis pouchetii* | $10^6$Cells $L^{-1}$ | ND | ND | ND |
| *Psuedo-nitzschia pungens* | $10^6$Cells $L^{-1}$ | ND | ND | ND |
| Total Zooplankton | Individuals $m^{-3}$ | 19,692 | 29,624 | 24,658 |

**Table 3-3. Nearfield Survey WN019 (Jul 01) Data Summary**

| **Region** | | **Nearfield** | | |
|---|---|---|---|---|
| **Parameter** | **Unit** | **Min** | **Max** | **Avg** |
| In Situ | | | | |
| Temperature | °C | 5.47 | 19.12 | 9.09 |
| Salinity | PSU | 31.2 | 32.5 | 31.6 |
| Sigma _T | | 22.1 | 25.5 | 24.4 |
| Beam Attenuation | $m^{-1}$ | 0.49 | 3.80 | 0.96 |
| DO Concentration | $mgL^{-1}$ | 8.98 | 11.16 | 9.75 |
| DO Saturation | PCT | 90.0 | 124.7 | 103.7 |
| Fluorescence | $\mu gL^{-1}$ | 0.02 | 7.55 | 1.49 |
| Chlorophyll a | $\mu gL^{-1}$ | 0.15 | 2.20 | 1.28 |
| Phaeopigment | $\mu gL^{-1}$ | 0.02 | 1.39 | 0.49 |
| Nutrients | | | | |
| NH4 | µM | 0.20 | 23.33 | 3.15 |
| NO2 | µM | 0.01 | 0.35 | 0.10 |
| NO2+NO3 | µM | 0.01 | 3.95 | 1.17 |
| PO4 | µM | 0.14 | 1.44 | 0.57 |
| SIO4 | µM | 0.26 | 7.60 | 3.01 |
| BIOSI | µM | 0.60 | 1.90 | 1.32 |
| DOC | µM | 153.7 | 417.7 | 235.6 |
| PARTP | µM | 0.06 | 0.37 | 0.22 |
| POC | µM | 2.64 | 35.30 | 18.67 |
| PON | µM | 0.81 | 5.90 | 3.04 |
| TDN | µM | 13.1 | 76.0 | 22.8 |
| TDP | µM | 0.46 | 1.02 | 0.73 |
| TSS | $mgL^{-1}$ | 0.16 | 0.95 | 0.70 |
| Urea | µM | 0.10 | 0.33 | 0.24 |
| Productivity | | | | |
| Alpha | $mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$ | 0.003 | 0.037 | 0.023 |
| Pmax | $mgCm^{-3}h^{-1}$ | 0.15 | 4.97 | 2.64 |
| Areal Production | $mgCm^{-2}d^{-1}$ | 311.8 | 666.6 | 489.2 |
| Depth-averaged Chlorophyll-specific Production | $mgC(mg\ Chla)^{-1}d^{-1}$ | 5.2 | 18.2 | 11.7 |
| Respiration | $\mu MO_2h^{-1}$ | 0.031 | 0.13 | 0.074 |
| Plankton | | | | |
| Total Phytoplankton | $10^6$Cells $L^{-1}$ | 1.726 | 4.493 | 3.290 |
| Centric diatoms | $10^6$Cells $L^{-1}$ | 0.135 | 0.356 | 0.230 |
| *Alexandrium spp.* | Cells $L^{-1}$ | 2.5 | 2.5 | 2.5 |
| *Phaeocystis pouchetii* | $10^6$Cells $L^{-1}$ | ND | ND | ND |
| *Psuedo-nitzschia pungens* | $10^6$Cells $L^{-1}$ | 0.0014 | 0.0014 | 0.0014 |
| Total Zooplankton | Individuals $m^{-3}$ | 15,270 | 45,356 | 30,313 |

**Table 3-4. Nearfield Survey WN01A (Aug 01) Data Summary**

| **Region** | | **Nearfield** | | |
|---|---|---|---|---|
| **Parameter** | **Unit** | **Min** | **Max** | **Avg** |
| In Situ | | | | |
| Temperature | °C | 5.81 | 20.40 | 10.46 |
| Salinity | PSU | 31.1 | 31.8 | 31.5 |
| Sigma _T | | 21.8 | 25.0 | 24.0 |
| Beam Attenuation | $m^{-1}$ | 0.56 | 1.53 | 0.92 |
| DO Concentration | $mgL^{-1}$ | | | |
| DO Saturation | PCT | | | |
| Fluorescence | $\mu gL^{-1}$ | 0.02 | 2.75 | 0.86 |
| Chlorophyll a | $\mu gL^{-1}$ | 0.10 | 2.38 | 0.84 |
| Phaeopigment | $\mu gL^{-1}$ | 0.19 | 0.87 | 0.42 |
| Nutrients | | | | |
| NH4 | μM | 0.21 | 19.78 | 3.58 |
| NO2 | μM | 0.01 | 0.48 | 0.13 |
| NO2+NO3 | μM | 0.01 | 5.20 | 1.34 |
| PO4 | μM | 0.19 | 1.39 | 0.61 |
| SIO4 | μM | 1.01 | 7.05 | 3.46 |
| BIOSI | μM | 0.50 | 7.80 | 1.44 |
| DOC | μM | 167.3 | 550.6 | 332.6 |
| PARTP | μM | 0.07 | 0.36 | 0.18 |
| POC | μM | 7.42 | 40.50 | 19.90 |
| PON | μM | 1.24 | 5.11 | 3.03 |
| TDN | μM | 13.9 | 78.4 | 25.1 |
| TDP | μM | 0.39 | 1.64 | 0.82 |
| TSS | $mgL^{-1}$ | 0.30 | 1.00 | 0.58 |
| Urea | μM | 0.60 | 1.69 | 1.08 |
| Productivity | | | | |
| Alpha | $mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$ | 0.002 | 0.069 | 0.026 |
| Pmax | $mgCm^{-3}h^{-1}$ | 0.19 | 5.10 | 2.30 |
| Areal Production | $mgCm^{-2}d^{-1}$ | 727.1 | 748.6 | 737.9 |
| Depth-averaged Chlorophyll-specific Production | $mgC(mg\ Chla)^{-1}d^{-1}$ | 17.0 | 34.8 | 25.9 |
| Respiration | $\mu MO_2h^{-1}$ | 0.021 | 0.174 | 0.072 |
| Plankton | | | | |
| Total Phytoplankton | $10^6$Cells $L^{-1}$ | 0.801 | 2.184 | 1.645 |
| Centric diatoms | $10^6$Cells $L^{-1}$ | 0.039 | 0.086 | 0.057 |
| *Alexandrium spp.* | Cells $L^{-1}$ | ND | ND | ND |
| *Phaeocystis pouchetii* | $10^6$Cells $L^{-1}$ | ND | ND | ND |
| *Psuedo-nitzschia pungens* | $10^6$Cells $L^{-1}$ | ND | ND | ND |
| Total Zooplankton | Individuals $m^{-3}$ | 47,276 | 50,494 | 48,885 |

**Table 3-5. Combined Farfield/Nearfield Survey WF01B (Aug 01) Data Summary**

| | | Farfield | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Region** | | **Boundary** | | | **Cape Cod Bay** | | | **Coastal** | | |
| **Parameter** | **Unit** | **Min** | **Max** | **Avg** | **Min** | **Max** | **Avg** | **Min** | **Max** | **Avg** |
| In Situ | | | | | | | | | | |
| Temperature | °C | 4.88 | 18.66 | 9.57 | 7.08 | 19.05 | 12.63 | 9.12 | 18.06 | 14.01 |
| Salinity | PSU | 31.3 | 32.2 | 31.8 | 31.3 | 31.7 | 31.5 | 31.2 | 31.6 | 31.4 |
| Sigma _T | | 22.4 | 25.4 | 24.4 | 22.2 | 24.8 | 23.7 | 22.4 | 24.5 | 23.3 |
| Beam Attenuation | $m^{-1}$ | 0.60 | 1.49 | 0.95 | 0.84 | 1.96 | 1.46 | 0.88 | 2.34 | 1.62 |
| DO Concentration | $mgL^{-1}$ | | | | | | | | | |
| DO Saturation | PCT | | | | | | | | | |
| Fluorescence | $\mu gL^{-1}$ | 0.02 | 4.45 | 0.91 | 0.27 | 6.95 | 2.63 | 0.54 | 6.33 | 2.96 |
| Chlorophyll a | $\mu gL^{-1}$ | 0.05 | 2.26 | 1.04 | 0.36 | 2.51 | 1.43 | 0.64 | 3.96 | 2.35 |
| Phaeopigment | $\mu gL^{-1}$ | 0.12 | 1.54 | 0.81 | 0.40 | 2.07 | 1.11 | 1.17 | 4.24 | 1.91 |
| Nutrients | | | | | | | | | | |
| NH4 | µM | 0.15 | 3.38 | 0.94 | 0.12 | 4.75 | 1.32 | 0.09 | 3.10 | 1.43 |
| NO2 | µM | 0.01 | 0.37 | 0.18 | 0.01 | 0.24 | 0.09 | 0.01 | 0.23 | 0.08 |
| NO2+NO3 | µM | 0.02 | 9.77 | 4.39 | 0.02 | 2.29 | 0.70 | 0.02 | 2.24 | 0.68 |
| PO4 | µM | 0.22 | 1.16 | 0.71 | 0.07 | 0.95 | 0.47 | 0.20 | 0.73 | 0.47 |
| SIO4 | µM | 1.11 | 14.37 | 6.29 | 1.01 | 11.34 | 3.96 | 1.01 | 6.76 | 3.31 |
| BIOSI | µM | 0.50 | 1.30 | 0.95 | 0.40 | 1.70 | 1.12 | 1.40 | 3.80 | 2.76 |
| DOC | µM | 127.4 | 278.3 | 218.5 | 137.6 | 172.0 | 154.5 | 156.5 | 257.3 | 196.8 |
| PARTP | µM | 0.07 | 0.23 | 0.15 | 0.18 | 0.35 | 0.27 | 0.13 | 0.44 | 0.31 |
| POC | µM | 11.90 | 29.90 | 24.78 | 22.10 | 41.00 | 33.32 | 20.80 | 42.20 | 33.82 |
| PON | µM | 2.26 | 6.04 | 4.18 | 3.89 | 5.26 | 4.78 | 3.24 | 6.66 | 5.18 |
| TDN | µM | 13.2 | 18.9 | 15.9 | 11.7 | 15.5 | 13.1 | 13.5 | 17.3 | 15.0 |
| TDP | µM | 0.54 | 1.08 | 0.76 | 0.53 | 0.99 | 0.80 | 0.54 | 0.85 | 0.72 |
| TSS | $mgL^{-1}$ | 0.26 | 0.89 | 0.55 | 0.68 | 1.07 | 0.84 | 0.80 | 1.87 | 1.26 |
| Urea | µM | 0.10 | 0.40 | 0.25 | 0.10 | 0.37 | 0.17 | 0.10 | 0.68 | 0.35 |
| Productivity | | | | | | | | | | |
| Alpha | $mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$ | | | | | | | | | |
| Pmax | $mgCm^{-3}h^{-1}$ | | | | | | | | | |
| Areal Production | $mgCm^{-2}d^{-1}$ | | | | | | | | | |
| Depth-averaged Chlorophyll-specific Production | $mgC(mg\ Chla)^{-1}d^{-1}$ | | | | | | | | | |
| Respiration | $\mu MO_2h^{-1}$ | | | | | | | | | |
| Plankton | | | | | | | | | | |
| Total Phytoplankton | $10^6$Cells $L^{-1}$ | 0.874 | 1.941 | 1.214 | 1.932 | 2.986 | 2.415 | 0.674 | 3.837 | 2.394 |
| Centric diatoms | $10^6$Cells $L^{-1}$ | 0.025 | 0.374 | 0.146 | 0.150 | 0.455 | 0.301 | 0.037 | 1.239 | 0.741 |
| *Alexandrium spp.* | Cells $L^{-1}$ | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| *Phaeocystis pouchetii* | $10^6$Cells $L^{-1}$ | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| *Psuedo-nitzschia pungens* | $10^6$Cells $L^{-1}$ | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Total Zooplankton | Individuals $m^{-3}$ | 23,941 | 77,075 | 50,508 | 60,863 | 79,389 | 70,126 | 32,589 | 62,987 | 49,807 |

## Table 3-5. Combined Farfield/Nearfield Survey WF01B (Aug 01) Data Summary (continued)

| Region | | Farfield | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Harbor | | | Offshore | | | Nearfield | | |
| **Parameter** | **Unit** | **Min** | **Max** | **Avg** | **Min** | **Max** | **Avg** | **Min** | **Max** | **Avg** |
| In Situ | | | | | | | | | | |
| Temperature | °C | 11.94 | 17.85 | 15.06 | 5.68 | 19.10 | 10.02 | 6.14 | 18.40 | 12.03 |
| Salinity | PSU | 30.6 | 31.5 | 31.2 | 31.3 | 32.1 | 31.7 | 31.3 | 32.0 | 31.6 |
| Sigma _T | | 21.9 | 23.8 | 23.0 | 22.2 | 25.3 | 24.3 | 22.4 | 25.1 | 23.9 |
| Beam Attenuation | $m^{-1}$ | 1.50 | 2.34 | 1.87 | 0.59 | 2.09 | 1.00 | 0.58 | 2.24 | 1.10 |
| DO Concentration | $mgL^{-1}$ | | | | | | | | | |
| DO Saturation | PCT | | | | | | | | | |
| Fluorescence | $\mu gL^{-1}$ | 0.11 | 3.39 | 2.29 | 0.02 | 5.01 | 1.28 | 0.02 | 8.21 | 1.55 |
| Chlorophyll a | $\mu gL^{-1}$ | 1.79 | 4.56 | 3.12 | 0.08 | 2.59 | 1.11 | 0.15 | 4.94 | 1.44 |
| Phaeopigment | $\mu gL^{-1}$ | 1.01 | 2.66 | 1.92 | 0.16 | 1.90 | 0.84 | 0.34 | 2.72 | 1.06 |
| Nutrients | | | | | | | | | | |
| NH4 | $\mu M$ | 0.67 | 4.06 | 1.61 | 0.20 | 7.20 | 1.72 | 0.11 | 12.04 | 1.89 |
| NO2 | $\mu M$ | 0.09 | 0.16 | 0.12 | 0.01 | 0.49 | 0.19 | 0.01 | 0.65 | 0.26 |
| NO2+NO3 | $\mu M$ | 0.10 | 1.27 | 0.62 | 0.02 | 9.74 | 4.24 | 0.02 | 7.71 | 2.05 |
| PO4 | $\mu M$ | 0.51 | 0.66 | 0.61 | 0.12 | 0.99 | 0.66 | 0.16 | 0.97 | 0.56 |
| SIO4 | $\mu M$ | 2.65 | 8.57 | 4.06 | 0.76 | 8.19 | 4.72 | 0.01 | 15.32 | 4.73 |
| BIOSI | $\mu M$ | 3.00 | 4.80 | 3.92 | 0.40 | 1.30 | 0.91 | 0.16 | 4.40 | 1.09 |
| DOC | $\mu M$ | 166.4 | 284.8 | 208.3 | 122.0 | 221.7 | 159.0 | 127.6 | 457.1 | 193.9 |
| PARTP | $\mu M$ | 0.27 | 0.43 | 0.36 | 0.08 | 0.31 | 0.18 | 0.07 | 0.43 | 0.23 |
| POC | $\mu M$ | 22.80 | 34.60 | 30.27 | 8.08 | 35.30 | 19.65 | 7.38 | 49.00 | 23.45 |
| PON | $\mu M$ | 3.92 | 6.06 | 5.32 | 1.30 | 5.38 | 3.01 | 1.32 | 7.50 | 3.80 |
| TDN | $\mu M$ | 11.3 | 17.5 | 15.2 | 11.2 | 20.6 | 15.2 | 12.1 | 23.5 | 15.5 |
| TDP | $\mu M$ | 0.72 | 0.96 | 0.82 | 0.41 | 1.06 | 0.78 | 0.40 | 1.07 | 0.75 |
| TSS | $mgL^{-1}$ | 1.27 | 3.16 | 2.01 | 0.30 | 1.26 | 0.57 | 0.22 | 3.16 | 0.77 |
| Urea | $\mu M$ | 0.10 | 0.61 | 0.22 | 0.33 | 0.47 | 0.40 | 0.10 | 1.03 | 0.38 |
| Productivity | | | | | | | | | | |
| Alpha | $mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$ | 0.076 | 0.117 | 0.098 | | | | 0.019 | 0.124 | 0.047 |
| Pmax | $mgCm^{-3}h^{-1}$ | 7.81 | 20.93 | 13.52 | | | | 1.43 | 12.82 | 3.99 |
| Areal Production | $mgCm^{-2}d^{-1}$ | | | 1998.6 | | | | 608.3 | 1534.4 | 1071.4 |
| Depth-averaged Chlorophyll-specific Production | $mgC(mg\ Chla)^{-1}d^{-1}$ | | | 23.0 | | | | 12.4 | 55.7 | 34.1 |
| Respiration | $\mu MO_2h^{-1}$ | 0.075 | 0.159 | 0.120 | 0.090 | 0.248 | 0.170 | 0.085 | 0.152 | 0.123 |
| Plankton | | | | | | | | | | |
| Total Phytoplankton | $10^6$Cells $L^{-1}$ | 1.440 | 2.835 | 2.399 | 1.393 | 2.266 | 1.835 | 0.600 | 2.603 | 1.624 |
| Centric diatoms | $10^6$Cells $L^{-1}$ | 0.420 | 1.266 | 0.929 | 0.022 | 0.230 | 0.126 | 0.013 | 0.254 | 0.119 |
| *Alexandrium spp.* | Cells $L^{-1}$ | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| *Phaeocystis pouchetii* | $10^6$Cells $L^{-1}$ | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| *Psuedo-nitzschia pungens* | $10^6$Cells $L^{-1}$ | ND | ND | ND | ND | ND | ND | 0.0011 | 0.0011 | 0.0011 |
| Total Zooplankton | Individuals $m^{-3}$ | 33,280 | 74,165 | 53,053 | 58,623 | 74,175 | 66,399 | 40,583 | 104,237 | 63,145 |

**Table 3-6. Nearfield Survey WN01C (Sep 01) Data Summary**

| **Region** | | **Nearfield** | | |
|---|---|---|---|---|
| **Parameter** | **Unit** | **Min** | **Max** | **Avg** |
| In Situ | | | | |
| Temperature | °C | 6.67 | 17.21 | 12.51 |
| Salinity | PSU | 31.3 | 32.2 | 31.7 |
| Sigma _T | | 22.9 | 25.2 | 23.9 |
| Beam Attenuation | $m^{-1}$ | 0.43 | 1.90 | 1.00 |
| DO Concentration | $mgL^{-1}$ | 7.58 | 9.47 | 8.43 |
| DO Saturation | PCT | 77.1 | 114.1 | 97.0 |
| Fluorescence | $\mu gL^{-1}$ | 0.02 | 5.86 | 1.61 |
| Chlorophyll a | $\mu gL^{-1}$ | 0.18 | 4.27 | 1.97 |
| Phaeopigment | $\mu gL^{-1}$ | 0.21 | 2.50 | 0.89 |
| Nutrients | | | | |
| NH4 | µM | 0.20 | 24.31 | 3.07 |
| NO2 | µM | 0.01 | 0.32 | 0.13 |
| NO2+NO3 | µM | 0.01 | 9.87 | 4.01 |
| PO4 | µM | 0.11 | 1.77 | 0.76 |
| SIO4 | µM | 0.60 | 10.25 | 5.11 |
| BIOSI | µM | 0.80 | 4.70 | 2.33 |
| DOC | µM | 111.9 | 226.8 | 157.1 |
| PARTP | µM | 0.09 | 0.50 | 0.30 |
| POC | µM | 6.29 | 54.80 | 29.97 |
| PON | µM | 0.91 | 6.96 | 4.37 |
| TDN | µM | 10.2 | 37.6 | 16.3 |
| TDP | µM | 0.41 | 1.57 | 0.90 |
| TSS | $mgL^{-1}$ | 0.31 | 2.98 | 1.20 |
| Urea | µM | 0.10 | 0.22 | 0.13 |
| Productivity | | | | |
| Alpha | $mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$ | 0.003 | 0.107 | 0.040 |
| Pmax | $mgCm^{-3}h^{-1}$ | 0.27 | 10.48 | 3.12 |
| Areal Production | $mgCm^{-2}d^{-1}$ | 593.1 | 1030.2 | 811.7 |
| Depth-averaged Chlorophyll-specific Production | $mgC(mg\ Chla)^{-1}d^{-1}$ | 11.4 | 57.6 | 34.5 |
| Respiration | $\mu MO_2h^{-1}$ | 0.012 | 0.160 | 0.097 |
| Plankton | | | | |
| Total Phytoplankton | $10^6$Cells $L^{-1}$ | 0.778 | 1.673 | 1.288 |
| Centric diatoms | $10^6$Cells $L^{-1}$ | 0.144 | 0.396 | 0.288 |
| *Alexandrium spp.* | Cells $L^{-1}$ | ND | ND | ND |
| *Phaeocystis pouchetii* | $10^6$Cells $L^{-1}$ | ND | ND | ND |
| *Psuedo-nitzschia pungens* | $10^6$Cells $L^{-1}$ | 0.0032 | 0.0051 | 0.0044 |
| Total Zooplankton | Individuals $m^{-3}$ | 31,230 | 36,776 | 34,003 |

**Table 3-7. Nearfield Survey WN01D (Oct 01) Data Summary**

| **Region** | | **Nearfield** | | |
|---|---|---|---|---|
| **Parameter** | **Unit** | **Min** | **Max** | **Avg** |
| In Situ | | | | |
| Temperature | °C | 7.81 | 13.47 | 11.98 |
| Salinity | PSU | 31.3 | 32.2 | 31.9 |
| Sigma _T | | 23.6 | 25.1 | 24.1 |
| Beam Attenuation | $m^{-1}$ | 0.63 | 1.56 | 1.02 |
| DO Concentration | $mgL^{-1}$ | 7.22 | 9.30 | 8.39 |
| DO Saturation | PCT | 74.6 | 108.3 | 96.4 |
| Fluorescence | $\mu gL^{-1}$ | 0.01 | 6.79 | 2.68 |
| Chlorophyll a | $\mu gL^{-1}$ | 0.28 | 5.57 | 2.71 |
| Phaeopigment | $\mu gL^{-1}$ | 0.38 | 2.24 | 1.05 |
| Nutrients | | | | |
| NH4 | µM | 0.26 | 10.84 | 1.63 |
| NO2 | µM | 0.01 | 0.29 | 0.11 |
| NO2+NO3 | µM | 0.01 | 9.71 | 2.59 |
| PO4 | µM | 0.22 | 1.78 | 0.61 |
| SIO4 | µM | 1.45 | 9.77 | 3.84 |
| BIOSI | µM | 0.38 | 3.49 | 1.73 |
| DOC | µM | 120.0 | 203.9 | 156.2 |
| PARTP | µM | 0.10 | 0.33 | 0.23 |
| POC | µM | 8.92 | 41.00 | 24.11 |
| PON | µM | 1.66 | 6.00 | 3.97 |
| TDN | µM | 10.3 | 85.9 | 20.4 |
| TDP | µM | 0.64 | 1.19 | 0.85 |
| TSS | $mgL^{-1}$ | 0.36 | 1.57 | 0.82 |
| Urea | µM | 0.10 | 0.32 | 0.18 |
| Productivity | | | | |
| Alpha | $mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$ | 0.016 | 0.189 | 0.126 |
| Pmax | $mgCm^{-3}h^{-1}$ | 2.03 | 17.96 | 12.49 |
| Areal Production | $mgCm^{-2}d^{-1}$ | 2699.9 | 2713.6 | 2706.8 |
| Depth-averaged Chlorophyll-specific Production | $mgC(mg\ Chla)^{-1}d^{-1}$ | 15.2 | 35.6 | 25.4 |
| Respiration | $\mu MO_2h^{-1}$ | 0.047 | 0.193 | 0.125 |
| Plankton | | | | |
| Total Phytoplankton | $10^6$Cells $L^{-1}$ | 1.097 | 2.416 | 1.837 |
| Centric diatoms | $10^6$Cells $L^{-1}$ | 0.181 | 0.366 | 0.267 |
| *Alexandrium spp.* | Cells $L^{-1}$ | ND | ND | ND |
| *Phaeocystis pouchetii* | $10^6$Cells $L^{-1}$ | ND | ND | ND |
| *Psuedo-nitzschia pungens* | $10^6$Cells $L^{-1}$ | 0.0014 | 0.0359 | 0.0122 |
| Total Zooplankton | Individuals $m^{-3}$ | 14,719 | 17,684 | 16,201 |

# Table 3-8. Combined Farfield/Nearfield Survey WF01E (Oct 01) Data Summary

| Region | | Farfield | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Boundary | | | Cape Cod Bay | | | Coastal | | |
| **Parameter** | **Unit** | **Min** | **Max** | **Avg** | **Min** | **Max** | **Avg** | **Min** | **Max** | **Avg** |
| In Situ | | | | | | | | | | |
| Temperature | °C | 6.98 | 12.58 | 10.57 | 10.95 | 13.61 | 12.69 | 8.52 | 12.08 | 10.68 |
| Salinity | PSU | 30.9 | 32.6 | 32.0 | 30.6 | 32.6 | 31.6 | 31.8 | 32.6 | 32.1 |
| Sigma _T | | 23.4 | 25.5 | 24.5 | 22.9 | 24.8 | 23.8 | 24.1 | 25.0 | 24.6 |
| Beam Attenuation | $m^{-1}$ | 0.38 | 1.05 | 0.69 | 0.64 | 1.37 | 1.03 | 0.66 | 2.15 | 1.16 |
| DO Concentration | $mgL^{-1}$ | 7.56 | 9.40 | 8.54 | 7.61 | 8.87 | 8.52 | 7.24 | 10.61 | 8.33 |
| DO Saturation | PCT | 77.5 | 108.0 | 94.3 | 84.3 | 102.7 | 97.9 | 77.3 | 118.6 | 92.1 |
| Fluorescence | $\mu gL^{-1}$ | 0.12 | 4.60 | 1.54 | 0.75 | 4.73 | 2.61 | 0.43 | 11.03 | 2.89 |
| Chlorophyll a | $\mu gL^{-1}$ | 0.06 | 3.49 | 1.66 | 1.04 | 3.21 | 2.14 | 0.74 | 4.69 | 2.14 |
| Phaeopigment | $\mu gL^{-1}$ | 0.18 | 1.70 | 0.78 | 0.56 | 2.21 | 1.22 | 0.48 | 1.89 | 1.13 |
| Nutrients | | | | | | | | | | |
| NH4 | μM | 0.13 | 1.55 | 0.82 | 0.44 | 1.86 | 1.19 | 0.50 | 6.00 | 1.76 |
| NO2 | μM | 0.01 | 0.21 | 0.10 | 0.01 | 0.23 | 0.11 | 0.16 | 0.39 | 0.30 |
| NO2+NO3 | μM | 0.01 | 11.03 | 3.88 | 0.02 | 3.36 | 1.38 | 1.53 | 9.47 | 5.39 |
| PO4 | μM | 0.28 | 1.09 | 0.62 | 0.25 | 0.65 | 0.46 | 0.48 | 1.09 | 0.81 |
| SIO4 | μM | 2.85 | 11.14 | 5.33 | 2.09 | 6.86 | 4.30 | 4.37 | 10.01 | 7.14 |
| BIOSI | μM | 0.67 | 1.65 | 1.11 | 0.77 | 2.99 | 1.31 | 1.48 | 2.78 | 2.27 |
| DOC | μM | 113.5 | 209.1 | 147.0 | 180.3 | 263.2 | 213.0 | 120.2 | 214.9 | 146.7 |
| PARTP | μM | 0.07 | 0.27 | 0.18 | 0.25 | 0.30 | 0.27 | 0.15 | 0.27 | 0.19 |
| POC | μM | 5.76 | 32.60 | 24.34 | 19.40 | 33.30 | 26.40 | 13.70 | 31.10 | 18.56 |
| PON | μM | 1.06 | 4.66 | 3.75 | 2.97 | 4.99 | 4.23 | 2.19 | 4.54 | 3.05 |
| TDN | μM | 9.94 | 20.83 | 14.79 | 13.63 | 89.47 | 40.08 | 16.90 | 22.18 | 19.57 |
| TDP | μM | 0.65 | 1.22 | 0.90 | 0.58 | 1.01 | 0.77 | 1.02 | 1.36 | 1.19 |
| TSS | $mgL^{-1}$ | 0.23 | 0.82 | 0.49 | 0.51 | 1.28 | 0.74 | 0.65 | 1.70 | 1.18 |
| Urea | μM | 0.10 | 0.10 | 0.10 | 0.10 | 0.25 | 0.14 | 0.10 | 0.10 | 0.10 |
| Productivity | | | | | | | | | | |
| Alpha | $mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$ | | | | | | | | | |
| Pmax | $mgCm^{-3}h^{-1}$ | | | | | | | | | |
| Areal Production | $mgCm^{-2}d^{-1}$ | | | | | | | | | |
| Depth-averaged Chlorophyll-specific Production | $mgC(mg\ Chla)^{-1}d^{-1}$ | | | | | | | | | |
| Respiration | $\mu MO_2h^{-1}$ | | | | | | | | | |
| Plankton | | | | | | | | | | |
| Total Phytoplankton | $10^6$Cells $L^{-1}$ | 1.478 | 1.994 | 1.666 | 1.194 | 1.887 | 1.559 | 0.831 | 1.775 | 1.247 |
| Centric diatoms | $10^6$Cells $L^{-1}$ | 0.234 | 0.362 | 0.299 | 0.109 | 0.226 | 0.178 | 0.272 | 0.739 | 0.417 |
| *Alexandrium spp.* | Cells $L^{-1}$ | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| *Phaeocystis pouchetii* | $10^6$Cells $L^{-1}$ | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| *Psuedo-nitzschia pungens* | $10^6$Cells $L^{-1}$ | 0.0035 | 0.0086 | 0.0061 | 0.0021 | 0.0084 | 0.0045 | 0.0004 | 0.0045 | 0.0024 |
| Total Zooplankton | Individuals $m^{-3}$ | 18,085 | 28,073 | 23,079 | 31,810 | 76,747 | 54,279 | 16,051 | 48,407 | 32,349 |

## Table 3-8. Combined Farfield/Nearfield Survey WF01E (Oct 01) Data Summary (continued)

| Region | | Farfield | | | | | | Nearfield | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Harbor | | | Offshore | | | | | |
| Parameter | Unit | Min | Max | Avg | Min | Max | Avg | Min | Max | Avg |
| In Situ | | | | | | | | | | |
| Temperature | °C | 10.72 | 12.18 | 11.56 | 7.10 | 13.09 | 10.05 | 7.15 | 12.38 | 10.07 |
| Salinity | PSU | 30.6 | 32.1 | 31.5 | 31.6 | 32.5 | 32.0 | 31.7 | 32.4 | 32.0 |
| Sigma _T | | 23.2 | 24.5 | 24.0 | 23.9 | 25.4 | 24.6 | 24.2 | 25.3 | 24.6 |
| Beam Attenuation | $m^{-1}$ | 1.13 | 1.84 | 1.63 | 0.42 | 1.56 | 0.85 | 0.50 | 1.63 | 0.97 |
| DO Concentration | $mgL^{-1}$ | 8.02 | 8.40 | 8.21 | 7.35 | 9.72 | 8.34 | 7.21 | 9.78 | 8.27 |
| DO Saturation | PCT | 88.4 | 93.5 | 92.1 | 75.0 | 110.3 | 91.1 | 74.7 | 111.5 | 90.4 |
| Fluorescence | $\mu gL^{-1}$ | 1.49 | 2.18 | 1.66 | 0.01 | 6.97 | 2.20 | 0.14 | 7.99 | 2.09 |
| Chlorophyll a | $\mu gL^{-1}$ | 1.51 | 2.28 | 1.97 | 0.09 | 4.79 | 2.17 | 0.15 | 6.04 | 2.12 |
| Phaeopigment | $\mu gL^{-1}$ | 0.90 | 1.60 | 1.19 | 0.18 | 2.44 | 1.20 | 0.27 | 3.18 | 1.16 |
| Nutrients | | | | | | | | | | |
| NH4 | µM | 1.15 | 5.13 | 3.18 | 0.19 | 3.54 | 0.95 | 0.18 | 26.73 | 1.62 |
| NO2 | µM | 0.01 | 0.37 | 0.26 | 0.01 | 0.34 | 0.13 | 0.01 | 0.37 | 0.23 |
| NO2+NO3 | µM | 5.16 | 6.75 | 5.63 | 0.02 | 11.34 | 5.15 | 0.02 | 11.77 | 6.17 |
| PO4 | µM | 0.83 | 1.35 | 1.01 | 0.39 | 1.62 | 0.80 | 0.45 | 2.31 | 0.86 |
| SIO4 | µM | 6.83 | 10.68 | 7.82 | 2.76 | 13.32 | 7.06 | 2.84 | 13.26 | 7.12 |
| BIOSI | µM | 2.53 | 4.05 | 3.21 | 0.66 | 2.17 | 1.46 | 1.01 | 2.74 | 1.87 |
| DOC | µM | 133.2 | 208.7 | 166.5 | 98.7 | 223.6 | 148.6 | 103.6 | 297.9 | 153.6 |
| PARTP | µM | 0.22 | 0.38 | 0.29 | 0.10 | 0.38 | 0.24 | 0.09 | 0.40 | 0.22 |
| POC | µM | 16.20 | 29.10 | 21.77 | 7.96 | 42.50 | 25.01 | 8.28 | 48.90 | 23.97 |
| PON | µM | 3.23 | 4.19 | 3.73 | 1.61 | 5.86 | 3.99 | 1.32 | 7.21 | 3.76 |
| TDN | µM | 16.73 | 24.20 | 20.69 | 10.32 | 21.09 | 14.70 | 9.57 | 21.13 | 16.15 |
| TDP | µM | 1.23 | 1.52 | 1.35 | 0.73 | 1.30 | 0.94 | 0.69 | 1.41 | 1.06 |
| TSS | $mgL^{-1}$ | 1.65 | 2.77 | 2.12 | 0.32 | 2.20 | 0.82 | 0.50 | 1.31 | 0.89 |
| Urea | µM | 0.10 | 0.25 | 0.18 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 |
| Productivity | | | | | | | | | | |
| Alpha | $mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$ | 0.064 | 0.106 | 0.090 | | | | 0.010 | 0.245 | 0.123 |
| Pmax | $mgCm^{-3}h^{-1}$ | 9.58 | 10.65 | 10.33 | | | | 1.19 | 23.81 | 11.14 |
| Areal Production | $mgCm^{-2}d^{-1}$ | | | 702.9 | | | | 1469.2 | 1922.1 | 1695.7 |
| Depth-averaged Chlorophyll-specific Production | $mgC(mg\ Chla)^{-1}d^{-1}$ | | | 13.2 | | | | 9.9 | 21.4 | 15.6 |
| Respiration | $\mu MO_2h^{-1}$ | 0.016 | 0.175 | 0.093 | 0.045 | 0.095 | 0.070 | 0.014 | 0.110 | 0.069 |
| Plankton | | | | | | | | | | |
| Total Phytoplankton | $10^6$Cells $L^{-1}$ | 0.812 | 1.368 | 1.183 | 1.344 | 2.612 | 2.121 | 1.200 | 2.236 | 1.823 |
| Centric diatoms | $10^6$Cells $L^{-1}$ | 0.243 | 0.422 | 0.307 | 0.263 | 0.479 | 0.391 | 0.235 | 0.799 | 0.471 |
| *Alexandrium spp.* | Cells $L^{-1}$ | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| *Phaeocystis pouchetii* | $10^6$Cells $L^{-1}$ | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| *Psuedo-nitzschia pungens* | $10^6$Cells $L^{-1}$ | 0.0007 | 0.0112 | 0.0047 | 0.0030 | 0.0124 | 0.0062 | 0.0045 | 0.0090 | 0.0072 |
| Total Zooplankton | Individuals $m^{-3}$ | 9,120 | 17,884 | 14,920 | 33,430 | 46,820 | 40,125 | 20,114 | 33,106 | 26,349 |

**Table 3-9. Nearfield Survey WN01F (Oct 01) Data Summary**

| **Region** | | **Nearfield** | | |
|---|---|---|---|---|
| **Parameter** | **Unit** | **Min** | **Max** | **Avg** |
| In Situ | | | | |
| Temperature | °C | 7.78 | 11.92 | 10.01 |
| Salinity | PSU | 30.9 | 32.5 | 32.0 |
| Sigma _T | | 23.8 | 25.4 | 24.6 |
| Beam Attenuation | $m^{-1}$ | 0.46 | 1.54 | 1.06 |
| DO Concentration | $mgL^{-1}$ | 7.03 | 10.04 | 8.84 |
| DO Saturation | PCT | 73.1 | 111.6 | 96.4 |
| Fluorescence | $\mu gL^{-1}$ | 0.00 | 6.36 | 2.98 |
| Chlorophyll a | $\mu gL^{-1}$ | 0.14 | 5.08 | 3.29 |
| Phaeopigment | $\mu gL^{-1}$ | 0.31 | 5.18 | 2.20 |
| Nutrients | | | | |
| NH4 | µM | 0.08 | 13.94 | 1.82 |
| NO2 | µM | 0.01 | 0.41 | 0.19 |
| NO2+NO3 | µM | 0.05 | 11.18 | 4.68 |
| PO4 | µM | 0.30 | 1.56 | 0.77 |
| SIO4 | µM | 3.52 | 12.17 | 7.29 |
| BIOSI | µM | 1.13 | 3.41 | 2.08 |
| DOC | µM | 140.9 | 242.4 | 174.6 |
| PARTP | µM | 0.07 | 0.40 | 0.28 |
| POC | µM | 6.74 | 46.20 | 30.25 |
| PON | µM | 1.19 | 7.06 | 4.92 |
| TDN | µM | 10.7 | 49.5 | 24.7 |
| TDP | µM | 0.75 | 1.38 | 0.98 |
| TSS | $mgL^{-1}$ | 0.62 | 1.27 | 0.93 |
| Urea | µM | 0.10 | 0.10 | 0.10 |
| Productivity | | | | |
| Alpha | $mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$ | 0.004 | 0.270 | 0.113 |
| Pmax | $mgCm^{-3}h^{-1}$ | 0.30 | 23.71 | 9.84 |
| Areal Production | $mgCm^{-2}d^{-1}$ | 1525.0 | 2360.1 | 1942.6 |
| Depth-averaged Chlorophyll-specific Production | $mgC(mg\ Chla)^{-1}d^{-1}$ | 11.1 | 23.7 | 17.4 |
| Respiration | $\mu MO_2h^{-1}$ | 0.038 | 0.147 | 0.111 |
| Plankton | | | | |
| Total Phytoplankton | $10^6$Cells $L^{-1}$ | 1.351 | 3.257 | 2.439 |
| Centric diatoms | $10^6$Cells $L^{-1}$ | 0.197 | 0.860 | 0.397 |
| *Alexandrium spp.* | Cells $L^{-1}$ | ND | ND | ND |
| *Phaeocystis pouchetii* | $10^6$Cells $L^{-1}$ | ND | ND | ND |
| *Psuedo-nitzschia pungens* | $10^6$Cells $L^{-1}$ | 0.0026 | 0.0082 | 0.0051 |
| Total Zooplankton | Individuals $m^{-3}$ | 22,930 | 34,651 | 28,790 |

**Table 3-10. Nearfield Survey WN01G (Dec 01) Data Summary**

| **Region** | | **Nearfield** | | |
|---|---|---|---|---|
| **Parameter** | **Unit** | **Min** | **Max** | **Avg** |
| In Situ | | | | |
| Temperature | °C | 8.23 | 9.43 | 8.93 |
| Salinity | PSU | 31.1 | 32.7 | 32.2 |
| Sigma _T | | 24.1 | 25.4 | 25.0 |
| Beam Attenuation | $m^{-1}$ | 0.79 | 1.49 | 1.18 |
| DO Concentration | $mgL^{-1}$ | 6.99 | 10.09 | 8.89 |
| DO Saturation | PCT | 73.3 | 108.4 | 94.5 |
| Fluorescence | $\mu gL^{-1}$ | 0.02 | 11.15 | 4.44 |
| Chlorophyll a | $\mu gL^{-1}$ | 0.19 | 11.20 | 4.86 |
| Phaeopigment | $\mu gL^{-1}$ | 0.23 | 12.59 | 1.74 |
| Nutrients | | | | |
| NH4 | μM | 0.27 | 20.90 | 3.84 |
| NO2 | μM | 0.10 | 0.55 | 0.30 |
| NO2+NO3 | μM | 0.24 | 11.82 | 5.09 |
| PO4 | μM | 0.45 | 1.57 | 0.89 |
| SIO4 | μM | 0.57 | 14.67 | 5.30 |
| BIOSI | μM | 1.00 | 6.10 | 4.16 |
| DOC | μM | 109.3 | 233.7 | 161.4 |
| PARTP | μM | 0.10 | 0.39 | 0.28 |
| POC | μM | 14.8 | 88.3 | 44.8 |
| PON | μM | 1.49 | 8.93 | 5.37 |
| TDN | μM | 11.9 | 45.0 | 21.9 |
| TDP | μM | 0.68 | 1.87 | 1.05 |
| TSS | $mgL^{-1}$ | 0.85 | 2.19 | 1.35 |
| Urea | μM | 0.28 | 0.39 | 0.32 |
| Productivity | | | | |
| Alpha | $mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$ | 0.009 | 0.334 | 0.244 |
| Pmax | $mgCm^{-3}h^{-1}$ | 1.18 | 30.60 | 22.35 |
| Areal Production | $mgCm^{-2}d^{-1}$ | 3250.4 | 3263.5 | 3257.0 |
| Depth-averaged Chlorophyll-specific Production | $mgC(mg\ Chla)^{-1}d^{-1}$ | 15.3 | 22.5 | 18.9 |
| Respiration | $\mu MO_2h^{-1}$ | 0.019 | 0.128 | 0.081 |
| Plankton | | | | |
| Total Phytoplankton | $10^6$Cells $L^{-1}$ | 1.225 | 2.086 | 1.671 |
| Centric diatoms | $10^6$Cells $L^{-1}$ | 0.479 | 1.096 | 0.849 |
| *Alexandrium spp.* | Cells $L^{-1}$ | ND | ND | ND |
| *Phaeocystis pouchetii* | $10^6$Cells $L^{-1}$ | ND | ND | ND |
| *Psuedo-nitzschia pungens* | $10^6$Cells $L^{-1}$ | 0.0056 | 0.0078 | 0.0067 |
| Total Zooplankton | Individuals $m^{-3}$ | 23,515 | 43,055 | 33,285 |

**Table 3-11. Nearfield Survey WN01H (Dec 01) Data Summary**

| **Region** | | **Nearfield** | | |
|---|---|---|---|---|
| **Parameter** | **Unit** | **Min** | **Max** | **Avg** |
| In Situ | | | | |
| Temperature | °C | 7.65 | 8.26 | 8.05 |
| Salinity | PSU | 32.0 | 32.4 | 32.1 |
| Sigma _T | | 24.9 | 25.2 | 25.0 |
| Beam Attenuation | $m^{-1}$ | 0.79 | 1.19 | 0.96 |
| DO Concentration | $mgL^{-1}$ | 8.25 | 9.84 | 9.59 |
| DO Saturation | PCT | 86.4 | 101.5 | 99.8 |
| Fluorescence | $\mu gL^{-1}$ | 0.50 | 3.70 | 1.96 |
| Chlorophyll a | $\mu gL^{-1}$ | 0.80 | 2.94 | 2.01 |
| Phaeopigment | $\mu gL^{-1}$ | 0.34 | 2.53 | 0.71 |
| Nutrients | | | | |
| NH4 | µM | 0.55 | 6.57 | 2.59 |
| NO2 | µM | 0.18 | 0.39 | 0.26 |
| NO2+NO3 | µM | 4.45 | 9.24 | 5.26 |
| PO4 | µM | 0.68 | 1.09 | 0.90 |
| SIO4 | µM | 3.56 | 9.44 | 4.83 |
| BIOSI | µM | 1.20 | 2.60 | 1.60 |
| DOC | µM | 119.5 | 249.7 | 170.6 |
| PARTP | µM | 0.15 | 0.27 | 0.21 |
| POC | µM | 11.9 | 28.3 | 19.1 |
| PON | µM | 2.24 | 5.16 | 3.02 |
| TDN | µM | 14.7 | 44.3 | 20.1 |
| TDP | µM | 1.04 | 1.33 | 1.17 |
| TSS | $mgL^{-1}$ | 0.66 | 1.37 | 0.99 |
| Urea | µM | 0.10 | 0.42 | 0.18 |
| Productivity | | | | |
| Alpha | $mgCm^{-3}h^{-1}(\mu Em^{-2}s^{-1})^{-1}$ | 0.047 | 0.091 | 0.067 |
| Pmax | $mgCm^{-3}h^{-1}$ | 4.93 | 8.65 | 6.91 |
| Areal Production | $mgCm^{-2}d^{-1}$ | 621.3 | 780.9 | 701.1 |
| Depth-averaged Chlorophyll-specific Production | $mgC(mg\ Chla)^{-1}d^{-1}$ | 8.9 | 23.0 | 15.9 |
| Respiration | $\mu MO_2h^{-1}$ | 0.028 | 0.087 | 0.071 |
| Plankton | | | | |
| Total Phytoplankton | $10^6$Cells $L^{-1}$ | 0.491 | 0.784 | 0.662 |
| Centric diatoms | $10^6$Cells $L^{-1}$ | 0.155 | 0.234 | 0.205 |
| *Alexandrium spp.* | Cells $L^{-1}$ | ND | ND | ND |
| *Phaeocystis pouchetii* | $10^6$Cells $L^{-1}$ | ND | ND | ND |
| *Psuedo-nitzschia pungens* | $10^6$Cells $L^{-1}$ | 0.0026 | 0.0146 | 0.0076 |
| Total Zooplankton | Individuals $m^{-3}$ | 15,801 | 30,539 | 23,170 |

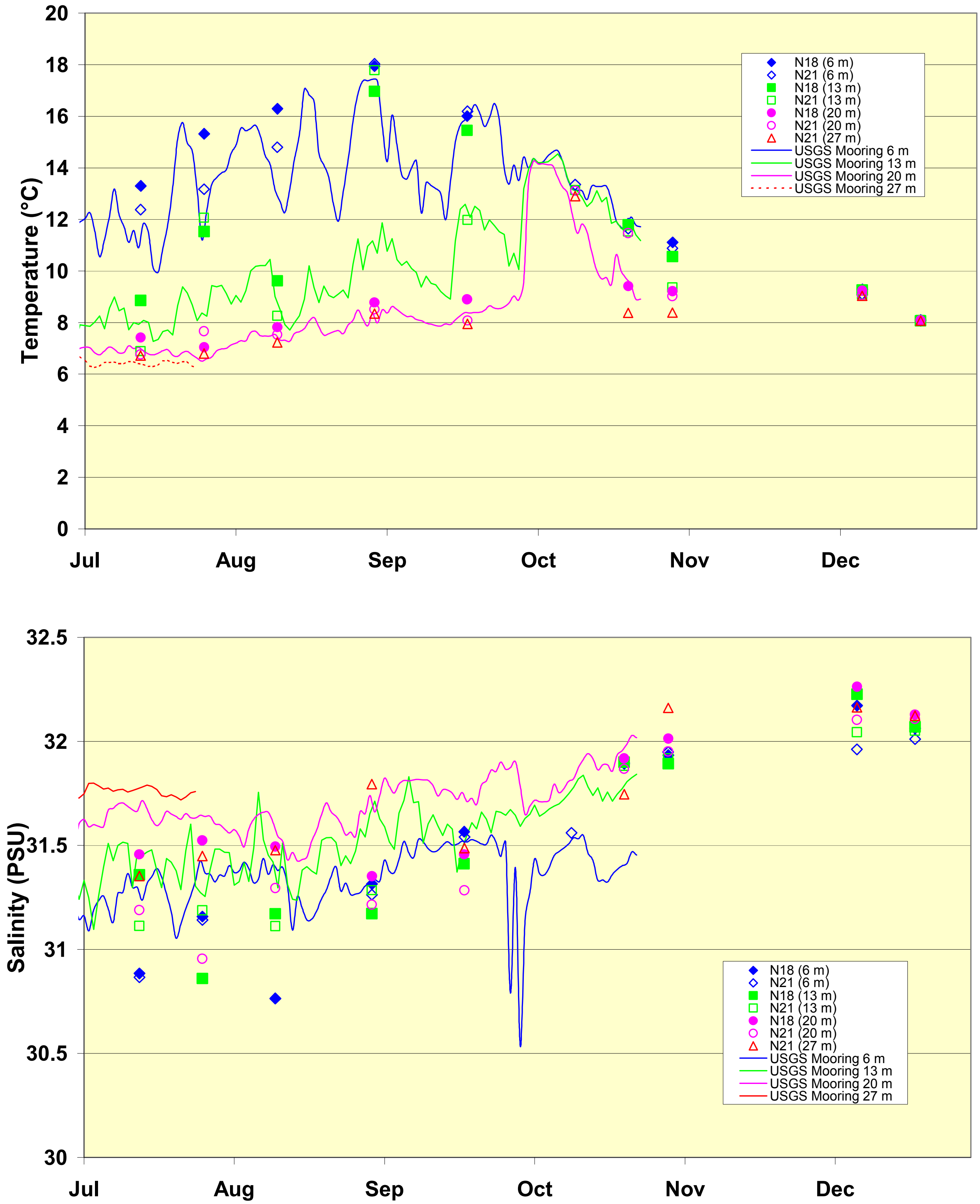



**Figure 3-1. USGS Temperature and Salinity Mooring Data Compared with Stations N18 and N21 data at comparable depths**

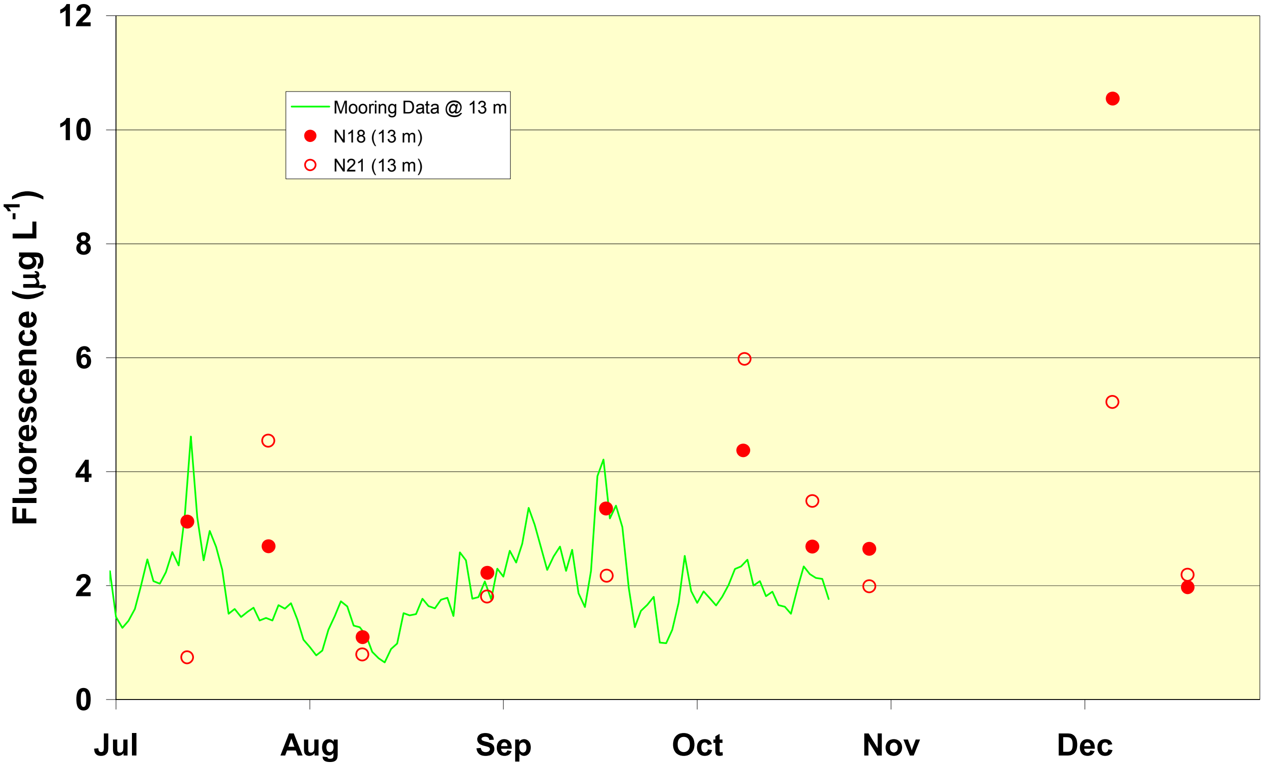



**Figure 3-2. MWRA and Battelle *In Situ* Wetstar Fluorescence Data (MWRA Data Acquired at ~13 m on USGS Mooring and Battelle Data Acquired at 13 m at Stations N18 and N21)**

# 4.0 RESULTS OF WATER COLUMN MEASUREMENTS

Data presented in this section are organized by type of data and survey. Physical data, including temperature, salinity, density, and beam attenuation are presented in Section 4.1. Nutrients, chlorophyll a, and dissolved oxygen are discussed in Section 4.2. Water quality measurements for chlorophyll a and dissolved oxygen are compared against Contingency Plan thresholds in Section 4.3. Finally, a summary of the major results for these water column measurements is provided in Section 4.4.

Two of the ten surveys conducted during this semi-annual period were combined farfield/nearfield surveys. In August during the first combined survey of this period (WF01B), seasonal stratification conditions existed throughout the bays. Stratification was relatively weak in tidally mixed Boston Harbor as normally observed. By October (WF01E), the density gradient had weakened across the bays and the water column was no longer stratified at the coastal and Boston Harbor stations. The change from stratified to well mixed conditions in the nearfield is illustrated in Figure 4-1. In the nearfield, stratification had weakened by early October, but a weak density gradient still existed until December when the water column finally returned to well-mixed winter conditions over the entire nearfield.

Data collected during the farfield surveys were evaluated for trends in regional water masses throughout Boston Harbor, Massachusetts Bay, and Cape Cod Bay. The variation of regional surface water properties is presented using contour plots of surface water parameters, derived from the surface (depth A) water sample. Classifying data by regions allows comparison of the horizontal distribution of water mass properties over the farfield area.

The vertical distribution of water column parameters is presented in the following sections along five transects (Boston-Nearfield, Cohassett, Marshfield, Boundary, and Nearfield-Marshfield) in the farfield survey area and one transect across the Nearfield (Figure 1-3). Examining data trends along transects provides a three-dimensional perspective of water column conditions during each survey. Nearfield surveys were conducted more frequently than farfield surveys, allowing better temporal resolution of the changes in water column parameters and destabilization of stratified conditions. In addition to the nearfield vertical transect (Figure 1-3), vertical variability in nearfield data is examined and presented by comparing surface and bottom water concentrations (A and E depths) and by plotting individual parameters with depth in the water column. A complete set of the surface contour maps, vertical transect plots, and parameter scatter plots is provided in Appendices B, C, and D, respectively.

## *4.1 Physical Characteristics*

### 4.1.1 Temperature\Salinity\Density

The breakdown of vertical stratification in the fall indicates the change from summer to winter conditions (Figure 4-2). This destabilization of the water column significantly affects a number of water quality parameters during this time period. From early September through October, the water column becomes less stratified and nutrients from the bottom waters are available to phytoplankton in the surface and mid-water depths. This often leads to the development of a fall bloom. Phytoplankton production and further mixing of the water column also serve to increase bottom water dissolved oxygen concentrations, which tend to decrease from early June through October.

The pycnocline weakens as surface water temperature declines and late fall/early winter storms increase wind-forced mixing. As mentioned above, the surface and bottom water density data collected during the combined surveys indicated that seasonal stratification had begun to weaken throughout the region by the October survey. Nearfield survey activities provide a more detailed evaluation of the fall/winter overturn of the water column. For the purposes of this report, vertical stratification is defined by the presence of a pycnocline with a density ($\sigma_t$) gradient of greater than 1.0 over a relatively narrow depth range (~10 m). Using this definition, the data indicate that the pycnocline began to break down in the western nearfield in October, but the water column was not well mixed until December (Figure 4-2). USGS mooring data indicated that there was a strong mixing event in late September, but that by early October the water column was once again stratified (see Figure 3-1).

#### 4.1.1.1 Horizontal Distribution

Over the course of the three nearfield surveys conducted in July and early August (WN018, WN019, and WN01A), there was an ~5°C increase in surface temperature across the nearfield area. In early July, surface water temperatures were cooler (<14°C) at nearshore stations N01 and N10 and relatively consistent (14.5 to 15°C) throughout the rest of the nearfield. In late July, there was a large gradient in temperature across the nearfield with the coolest temperatures in the northwest corner (12.2°C at station N01) and the warmest to the south (19.1°C at station N09). This does not appear to be a function of sampling time as cool surface waters were observed later in the day to the north (stations N12 and N13) and warm surface waters were observed earlier in the day to the south (stations N08, N17 and N18). By early August, surface water temperatures had warmed to >17.5°C in the nearfield with the coolest temperatures inshore and warmest offshore (17.6°C at station N11 to 20.4°C at station N07). Surface salinity was lower (~0.5 PSU) in early July in comparison to the two subsequent surveys. During all three surveys, however, there was little variation in surface salinity (30.6 to 31.0 PSU during WN018 and 31.1 to 31.5 for WN019 and WN01A) with the surface waters at inshore stations slightly less saline than at the offshore stations.

In August (WF01B), surface water temperatures were coolest (<16°C) in Boston Harbor and at boundary stations F26 and F27 off of Cape Ann (Figure 4-3). Elevated surface temperatures (>18°C) were found in Cape Cod Bay and at a few nearfield and offshore stations. The warmer temperatures at nearfield (N09, N19, and N20) and offshore (F15 and F16) stations was due to diurnal warming as these stations were sampled late in the day – rather than a spatial difference in surface water temperatures. Surface water salinity was homogeneous across the bays ranging from 31.2 PSU at outer Boston Harbor stations F23 and F31 to 31.5 PSU at station F12 in Stellwagen basin. Surface salinity was slightly lower at inner harbor station F30 (30.6 PSU). No clear upwelling signal of cooler more saline waters was observed for the surface data in the coastal waters in August 2001. Local climatological data from the National Weather Service station at Logan Airport indicated wind speeds were below normal and the direction of prevailing winds was inconsistent in August. Stronger winds and instances of prevailing southwesterly winds in July led to upwelling favorable conditions in July. This will be presented in more detail in the annual report.

During the nearfield survey conducted in September (WN01C), surface temperatures ranged from a low of 14.1°C at station N10 to a high of 17.2°C at station N03 and a trend of increasing surface temperature from southwest to northeast was observed across the nearfield. Nearfield surface salinity was homogeneous in September (31.5 PSU). By early October, surface temperatures had decreased to 13 to 13.5°C across the nearfield and salinity ranged from 32 PSU nearshore to 31.5 PSU offshore. There was a relatively large increase in flow in the Merrimack River in late September (Figure 4-4) that may have contributed to lower offshore salinities. It is unclear how much of an effect this increase in river flow would have had in Massachusetts Bay as even though the Merrimack River reached peak flow on September 27th for this July to December time period, the flow was only

5,000 cfs, which is usually the minimum flow recorded (see Libby *et al*. 2001a). The low flows were correlated with very little precipitation, as there were no rain events in September to December that totaled an inch or more during this very mild, sunny and dry fall of 2001. The low flows measured for both the Charles and Merrimack Rivers and the drought conditions during the fall of 2001 will be discussed in more detail in the 2001 annual report.

The October combined survey (WF01E) was conducted over the course of nine days, but there did not appear to be any relationship between the sampling date and the trends in temperature and salinity (Figures 4-5 and 4-6). There was a clear north to south gradient of increasing temperature from a minimum surface temperature of 10.7°C at station N01 and a maximum of 13.6 at Cape Cod Bay station F02. Cooler waters were located in the northern nearfield, Boston Harbor and along the North Shore from the harbor to Cape Ann. Surface water salinity in most of Massachusetts Bay was 32 PSU with values decreasing to the south into Cape Cod Bay (<31 PSU at stations F02 and F03) and Boston Harbor where the lowest surface salinity was measured at station F31. The slightly fresher waters were likely due to the October 16$^{th}$ rain event. The cooler, yet not fresher, surface waters at coastal and nearfield stations were the result of cooler atmospheric temperatures and increased mixing between surface and deeper waters. In late October during the nearfield survey (WN01F), temperature and salinity increased from minimum values at station N01 (10.1°C and 30.9 PSU) to maximum values to the southeast at stations N07 (11.9°C) and N16 (32.0 PSU). It is unclear as to the source of the fresher, cooler waters (no apparent meteorological factors), but it likely due to a more regional inshore to offshore trend and not a surfacing of the effluent plume as the nearfield was still slightly stratified (see Figure 4-2).

During the December nearfield surveys (WN01G and WN01H), lower temperatures and lower salinity were observed in the surface waters along the western nearfield. Surface temperatures decreased to 8.5 to 9.4 °C in early December and were about a degree cooler (7.6-8.2 °C) by the late December survey. Surface salinity exhibited a relatively wide range of values in early December (from 31 PSU at station N01 to 32.3 PSU at station N06), but by late December there was a relatively small inshore to offshore gradient (32-32.2 PSU).

#### 4.1.1.2 Vertical Distribution

**Farfield.** The water column was stratified throughout the bays during the summer of 2001, but remained relatively well mixed in Boston Harbor. By October, stratified conditions had begun to deteriorate in coastal waters although it did not become well mixed until December in the nearfield and likely in the other offshore waters of Massachusetts and Cape Cod Bays. As suggested previously, the density gradient ($\Delta\sigma_t$), representing the difference between the bottom and surface water $\sigma_t$, can be used as a relative indicator of a mixed or vertically stratified water column. During the August farfield survey (WF01B), the $\Delta\sigma_t$ between surface and bottom waters was >1 throughout the region except at the Boston Harbor stations (Figure 4-7). These stations are shallow and subject to strong tidal mixing. Surface water densities had increased by the October survey across the region and the water column was only well mixed at the harbor and coastal stations, as $\Delta\sigma_t$ had decreased to <1. At the Cape Cod Bay, offshore and boundary area stations, stratification had weakened, but the density difference between bottom and surface waters was still >1. During both of the combined surveys, there was little variation in salinity over the water column in the harbor, coastal, offshore and boundary areas (≤0.5 PSU). In Cape Cod Bay, the salinity gradient was 0.2 PSU in August and increased to >1 PSU by October, which contributed to the continued density gradient of >1 in October. For the offshore and boundary stations, the density difference was driven by the continued gradient in temperature over the water column. Temperatures had decreased in the surface waters, but there was still a 3-4°C gradient at these deeper stations.

The temporal and spatial variability during the seasonal return to well-mixed winter conditions is also observed in the vertical contour plots of temperature, salinity, and sigma-*t* for the Boston-Nearfield, Cohassett, and Marshfield transects (Appendix C). In August, the water column was strongly stratified along each of the transects ($\Delta\sigma_t$ >2; Figure 4-8) and a sharp pycnocline was observed at 15-20 m. The gradient was weaker at the inshore stations along each of the transects and $\Delta\sigma_t$ was <1 at Boston Harbor station F23. The density gradient was driven by temperature, which exhibited a >8°C difference between the surface and bottom layers at all but the nearshore stations along each transect (Figure 4-9). There was only a small increase in salinity from surface to bottom waters, as salinity remained >31 PSU over each of the transects. An upwelling signature of cooler, more saline water extending from the bottom waters into the surface or near surface waters was not evident in the temperature and salinity contours. By October, stratification had weakened throughout the region. As mentioned above, $\Delta\sigma_t$ between surface and bottom waters was <1 at the nearshore stations and ~1 further offshore where the water column continued to be weakly stratified (Figure 4-10). The decrease in $\Delta\sigma_t$ was driven by changes in surface and bottom water temperatures. Decreasing air temperatures and mixing cooled the surface waters, while bottom waters continued to be warmed due to mixing with warmer mid-depth waters.

The return to winter conditions and the change in temperature relative to salinity can also be seen by examining the temperature-salinity (T-S) relationship for the region. In Figure 4-11, the T-S plots for the August and October surveys are presented. In August (WF01B), the T-S pattern is indicative of the vertical stratification that exists in the bays during the summer season. Surface water temperatures were generally 17-19°C and there was a strong thermal gradient (8-12°C) between surface and bottom water temperatures across the bays. Salinity varied over a relatively narrow range (31.2-32.2 PSU) except for slightly lower salinity at the shallow Boston Harbor stations. There was a negative relationship between the parameters as an increase in salinity with depth was coincident with a decrease in temperature. By October (WF01E), the range in temperatures had decreased (7 to 14°C) as temperatures had decreased in the surface waters and increased in the bottom waters. The range in salinity remained about the same though salinity had increased by ~0.3 throughout Massachusetts Bay (31.5-32.5 PSU). The T-S pattern at the offshore, boundary, and nearfield areas continued to exhibit the summer signature of increasing salinity corresponding to decreasing temperature from the surface to the bottom waters. In Boston Harbor and Cape Cod Bay, the T-S pattern was shifting towards the characteristics of a well-mixed winter water column – with minimal variation in temperature although there was a relatively wide range in salinity in these areas. In Boston Harbor, the salinity variability was due to spatial and temporal differences – the lower salinity values were measured at station F31 about a week after measurements were made at stations F23 and F30. In Cape Cod Bay, salinity decreased from north (station F03) to south (stations F01 and F02), but there was also a relatively large gradient in salinity between the surface and bottom waters. The prolonged period of weak stratification continued to be observed following the October survey at the nearfield stations and it is expected that similar conditions were present in offshore Massachusetts and Cape Cod Bay waters.

**Nearfield.** The gradual breakdown of seasonal stratification in 2001 and the eventual return to winter conditions can be observed more clearly from the data collected in the nearfield area. The nearfield surveys are conducted on a more frequent basis and later into the winter and thus provide a more detailed picture of the physical characteristics of the water column. In Figure 4-1, it was suggested that the breakdown of stratification proceeded from the shallow inshore stations to the deeper offshore stations. In late October, the inner nearfield stations (N10 and N11) exhibited a small density gradient ($\Delta\sigma_t$ ~0.5), while in Broad Sound (N01) and the outer nearfield stations (N04, N07, N16, and N20) the water column was still stratified ($\Delta\sigma_t \geq 1$). By early December (WN01G), the inner nearfield was well mixed and only a weak density gradient ($\Delta\sigma_t$ ~0.5) was observed in the outer nearfield. At station N01, the water column continued to be stratified due to lower salinity surface waters. By late December, the entire nearfield area was well mixed and had finally returned to winter conditions. Figures 4-12 and 4-13 present sigma-*t* along the nearfield transect (see Figure 1-3) from mid September to late December showing the progression in the destabilization of the water column during the fall of 2001. In September, stratified conditions were present along the entire nearfield transect and the pycnocline was observed at 15 m though it was not as clearly defined as during the August surveys (see Figure 4-9). USGS mooring data showed a sharp increase in temperature at 13 and 20 m and uniformity in temperature from 6 to 20 m (14° C, see Figure 3-1). This was coincident with a sharp decrease in surface salinity (6m). Thus, it is likely that the density gradient persisted from September to early October. By early October mooring data indicated a gradient from 6 to 20 m in both temperature and salinity was present. The early October (WN01D) monitoring data showed that the density gradient had decreased and fairly well mixed conditions were observed in the western nearfield, while in the eastern nearfield the water column was still stratified with a deep pycnocline near 30 m. During the mid and late October surveys (WF01E and WN01F), the water column continued to be fairly well mixed in the eastern nearfield and exhibited a density gradient of ~1 at the eastern nearfield stations. By early December, winter physical characteristics were present along the nearfield transect except furthest offshore at station N04 where there was still a gradient in density ($\Delta\sigma_t$ >0.5) between the surface and deep waters. During the final survey of 2001, the water column was well mixed throughout the nearfield.

The vertical gradient in density is predominantly driven by temperature during the fall in Massachusetts and Cape Cod Bays, as was the case in 2001. In September, there was a very strong temperature gradient (8-10°C) between surface and bottom waters and a sharp thermocline at 15 m along the nearfield transect (Figure 4-14). By early October, increased mixing of surface and deeper waters led to a decrease in surface water temperatures (13-15°C) and warmer water temperatures at depth (>11°C down to 30 m thermocline). Over the course of the month of October, surface water temperatures continued to decrease due to atmospheric cooling and mixing and by the end of the month there was only a 2-3°C gradient between surface and bottom waters. A weak temperature gradient persisted into December, but by the late December survey water temperatures were 7.6-8.3°C throughout the nearfield.

In addition to the harbor, coastal and offshore influences on nearfield physical conditions, MWRA effluent has been discharged directly into the nearfield area since the transfer from the harbor outfall to the bay outfall on September 6, 2000. Plume tracking studies and monitoring data have indicated that the region of rapid initial dilution is tightly constrained to the local area around the diffuser. Even so, the salinity data shows an effluent derived influence albeit at very high dilutions. The salinity signal of the discharge was more clearly seen during the summer period from July into September in part due to strong stratification and confinement of the plume below the pycnocline than later in the fall (Figure 4-15). Increased mixing and the lack of rain that resulted in very low effluent flow rates led to a less defined salinity signal for the plume during the fall of 2001. Note, however, that the lower flow rates did not necessarily equate to lower nutrient loading as the nutrient concentrations in the effluent increased as flow decreased and the nutrient signature of the plume was clearly observed throughout the fall of 2001 (see Section 4.2.1). During both the late August and September surveys (WF01B and WN01C), a core of lower salinity water was observed below the pycnocline at station N21 directly over the diffuser and the vertical contours of the data suggest that the salinity signature of the plume extended to nearby nearfield stations. This is also shown in contour plots along the Boston-Nearfield and Nearfield-Marshfield transects (Figure 4-16). Along the E-W Boston-Nearfield transect, there are boluses of lower salinity water both to the east and west of station N21. It is unclear if the effluent plume actually extended to the harbor at station F23 or if this is a convergence of outfall and harbor lower salinity water. The more interesting salinity trend is the extension of lower salinity water from the nearfield (station N18 is 2 km south of the diffuser) to the south along the Nearfield-Marshfield transect. A similar trend was observed in the ammonium data (see Figure 4-27). The transport of highly diluted effluent discharge south of the nearfield area was predicted by the modeling studies.

### 4.1.2 Transmissometer Results

Water column beam attenuation was measured synoptically with the other *in situ* measurements at all nearfield and farfield stations. The transmissometer determines beam attenuation by measuring the percent transmission of light over a given path length in the water. The beam attenuation coefficient ($m^{-1}$) is indicative of particulate concentration in the water column. The two primary sources of particles in coastal waters are biogenic material (plankton or detritus) and suspended sediments. Beam attenuation data is often evaluated in conjunction with fluorescence data to ascertain the source of the particulate materials (phytoplankton versus detritus or suspended sediments).

In August (WF01B), surface water beam attenuation ranged from 1.1 $m^{-1}$ at station F22 in northern Stellwagen Basin to 2.3 $m^{-1}$ at station F30 in Boston Harbor (Figure 4-17). As is normally observed, elevated beam attenuation measurements were found at the harbor stations. An inshore to offshore decrease in beam attenuation was evident. A similar inshore to offshore decrease in surface water beam attenuation was observed during the October farfield survey (Figure 4-18). The highest value was measured at station F18 (2.2 $m^{-1}$) in the coastal waters off of Nahant and the lowest value was observed at station F29 off of Provincetown (0.7 $m^{-1}$). During both of the farfield surveys, the elevated beam attenuation values at the inshore nearfield and coastal stations were coincident with higher surface fluorescence and both parameters exhibited very similar patterns (see Figures 4-32 and 4-34). In October, the highest and lowest surface fluorescence values were observed at stations F18 and F29, respectively.

In general, the vertical and horizontal trends in beam attenuation are dependent upon the input of particulate material from terrestrial sources (inshore stations) and the distribution of chlorophyll/phytoplankton (offshore stations). Figure 4-19 presents beam attenuation data along the Boston-Nearfield transect in August and October. These contour plots clearly show the harbor signature of high beam attenuation (station F23) and its influence on nearshore stations. The beam attenuation signal further offshore during each survey is likely due to phytoplankton as the elevated beam attenuation values are coincident with higher chlorophyll concentrations (see Figures 4-36 and 4-37). During high-resolution plume tracking studies in 2001, a clear signature of elevated beam attenuation was associated with the effluent plume. This was not evident in the lower resolution sampling conducted during the water quality monitoring studies.

## *4.2 Biological Characteristics*

### 4.2.1 Nutrients

Nutrient data were initially analyzed using scatter plots of nutrient depth distribution, nutrient/nutrient relationships, and nutrient/salinity relationships (Appendix D). As observed with the physical characteristics, surface water contour maps (Appendix B) and vertical contours of nutrient data from select transects (Appendix C) were also produced to illustrate the spatial variability of these parameters.

The general trend in nutrient concentrations during the 2001 July to December period was similar to previous baseline monitoring years. Seasonal stratification led to the persistent nutrient depleted conditions in the surface and mid-depth waters and ultimately to an increase in nutrient concentrations in bottom waters due to increased rates of respiration (see Section 5.2) and remineralization of organic matter. In the fall, nutrient concentrations began to increase with the breakdown of stratification and possibly an early September upwelling event. Concentrations decreased in early October during the initiation of a fall bloom, but rebounded by late October due to continued weak mixing supplying nutrients to the surface waters and a decrease in biological utilization. In early December, nutrient concentrations had decreased again as the water column remained weakly stratified and production rates and chlorophyll concentrations peaked at both of the productivity stations during the late fall/winter bloom. By late December, nutrient concentrations returned to more typical winter values as the water column became well mixed.

Elevated concentrations of ammonium ($NH_4$) continued to be measured within the nearfield due to the diversion of flow from the harbor outfall to the bay outfall on September 6, 2000. The $NH_4$ plume signature both within and extending out of the nearfield continued to be observed and is one of the main focuses of this section.

#### 4.2.1.1 Horizontal Distribution

In August (WF01B), surface water nutrient concentrations were low throughout the bays. The highest nutrient concentrations were found in the nearfield [dissolved inorganic nitrogen (DIN) = 1.86 μM and $NH_4$ = 1.38 μM at station N10) and Boston Harbor [nitrate ($NO_3$) = 0.54 μM and phosphate ($PO_4$) = 0.64 μM at station F23]. Surface water DIN and $NH_4$ concentrations were elevated in the vicinity of Boston Harbor and decreased further offshore (Figure 4-20). Surface $NO_3$ and $PO_4$ concentrations were depleted throughout Massachusetts and Cape Cod Bays. Silicate ($SiO_4$) concentrations were variable with elevated surface values measured in the nearfield, Boston Harbor and northern Massachusetts Bay, while lower concentrations (<2 μM) were found over southern Massachusetts Bay and Cape Cod Bay (Appendix B).

By October (WF01E), surface nutrient concentrations had increased to relatively high levels in Boston Harbor and western Massachusetts Bay. The highest surface nutrient concentrations were observed in Boston Harbor (DIN = 9.77 μM, $NH_4$ = 4.33 μM and $PO_4$ = 1.35 μM at station F30 and ($SiO_4$ = 8.54 μM) at station F31) and at coastal station F24 ($NO_3$ = 6.24 μM). The pattern in surface $NO_3$ concentrations was typical of the other nutrients (Figure 4-21). Higher nutrient concentrations were measured in the surface waters of Boston Harbor and along the north and south shore. There was a gradient of decreasing concentrations from the northwest to the southeast corner of the nearfield. Surface nutrients continued to be present at low to depleted levels in this corner of the nearfield (stations N06, N07, N08, and N09), further offshore in Massachusetts Bay, and in southern Cape Cod Bay (see Appendix B). The elevated concentrations at coastal and nearfield stations were coincident with cooler surface temperatures and, as suggested in Section 4.1, likely the result of increased mixing of surface and deeper waters.

Although elevated nutrient concentrations continue to be measured in Boston Harbor in 2001, the concentrations were substantially lower than the concentrations measured during August and October surveys during baseline years. This is obviously due to the diversion of MWRA effluent from the harbor outfall to the bay outfall. The usefulness of $NH_4$ as a tracer of the effluent plume has been clearly established in previous reports (Libby *et al*., 2001a, 2001b, and 2002). Although it is not a conservative tracer due to biological utilization, $NH_4$ concentration does provide a good tracer of the effluent plume especially in low light conditions where biological activity is minimal (i.e. below the pycnocline during stratified conditions and during the winter). A comparison of $NH_4$ concentrations in August 2000 and 2001 illustrates just how remarkable a change it was (Figures 4-22 and 4-23). Surface water $NH_4$ concentrations were high in the harbor in 2000 and low in 2001. At mid-depth, $NH_4$ concentrations were high in the harbor and low in the bays in 2000, while concentrations were low in the harbor, high in the nearfield in the vicinity of the outfall, and elevated concentrations appeared to extend south of the nearfield in 2001. Since the water column was strongly stratified in August 2001, the elevated $NH_4$ concentrations associated with the effluent discharge into the bay were not observed in the surface waters, but rather were contained below the pycnocline. As suggested in Section 4.1, the effluent plume appeared to be advected to the south during the late August survey and the extent of the plume (as indicated by elevated $NH_4$ concentrations) to the south of the outfall was clearly observed in both mid-depth and mid-bottom waters (Figure 4-24).

The distribution of $NH_4$ concentrations at each sampling depth across the nearfield under stratified and well-mixed conditions is presented in Figure 4-25. In late July, the water column was strongly stratified and high $NH_4$ concentrations were measured at deeper depths, while in December, after stratification had weakened, the effluent plume had reached the surface and extended over much of the nearfield. Ammonium concentrations continue to be an excellent tracer of the effluent plume and provide valuable information on plume location and spatial (vertical and horizontal) distribution. The use of $NH_4$ concentration data measured for both the effluent discharged from the Deer Island Treatment Plant and in Massachusetts Bay to estimate dilution rates will be explored in the 2001 annual water column report.

#### 4.2.1.2 Vertical Distribution

**Farfield.** The vertical distribution of nutrients was evaluated using vertical contours of nutrient data collected along the farfield transects (Figure 1-3; Appendix C). In late August (WF01B), nutrient concentrations were low in the surface waters and increased with depth. As observed along the Boston-Nearfield transect (Figure 4-26), $NO_3$, $PO_4$, and $SiO_4$ concentrations were low in the surface waters and increased near the pycnocline and closer to Boston Harbor. Nitrate was depleted (<1 µM) at the surface and only reached concentrations of >3 µM below a depth of 20 m. The vertical pattern for $PO_4$ and $SiO_4$ was similar to that of $NO_3$, but the concentrations were not as depleted in the surface layer. As is usually the case, the summer pattern of depleted nutrients in the surface waters was concomitant with low chlorophyll concentrations and a sub-surface chlorophyll maximum was observed near the pycnocline and associated available nutrients (see Section 4.2.2.2).

The vertical distribution of $NH_4$ concentrations extending from the nearfield to the south that was mentioned previously is evident in the vertical contours along both the Boston-Nearfield and Nearfield-Marshfield transects (Figure 4-27). High $NH_4$ concentrations (5-13 µM) were measured over all but the surface waters at station N21 and elevated concentrations (>3 µM) extended both west and east along the Boston-Nearfield transect. Elevated $NH_4$ concentrations also extended from the nearfield to station F06 along the Nearfield-Marshfield transect suggesting advection of the plume to the south. Within this advected plume, $NH_4$ was measured at higher concentrations than $NO_3$ and was the main source of nitrogen for phytoplankton in these waters.

In October (WF01E), $NO_3$ concentrations were still depleted in the surface waters at the offshore stations along each of the transects and increased with depth (Figure 4-28 and Appendix C). Although $PO_4$ and $SiO_4$ data exhibited a similar trend decreasing from inshore to offshore in the surface waters, concentrations of these nutrients were not as depleted as $NO_3$ (Figure 4-28). Elevated nutrient concentrations were present over the entire water column at the harbor, coastal and western nearfield stations, which had become relatively well mixed. Higher nutrient concentrations were also found in the bottom water at these inshore stations (relative to the August survey), which suggests an influx of bottom waters perhaps due to regeneration, upwelling, or advection. The availability of nutrients in the surface waters was coincident with and contributed to elevated chlorophyll concentrations. One clear feature of the $PO_4$ distribution was the elevated concentrations located above the diffuser at station N21 (Figure 4-28b). This was coincident with very high $NH_4$ concentrations (>17 µM) that were present in the effluent plume (Figure 4-29). Both of these nutrients are enriched in the effluent in comparison to background concentrations in the nearfield. Based on $NH_4$ concentrations, the plume appears to have been confined within the nearfield area and below the pycnocline in October in contrast with August when it extended to the south and later in the year when the nearfield was well mixed and it reached the surface.

**Nearfield.** The nearfield surveys are conducted more frequently and provide a higher resolution of the temporal variation in nutrient concentrations over the semi-annual period. In previous sections, the transition from summer to winter physical and nutrient characteristics has been discussed. For most of the nearfield, summer conditions of depleted nutrient concentrations in the surface waters existed until late October (WN01F) and did not return to nutrient replete winter conditions until late December (WN01H). The progression from summer to winter conditions is illustrated in the series of nearfield transect plots for $NO_3$ presented in Figures 4-30 and 4-31. In August (WF01B), $NO_3$ concentrations were depleted (<1 µM) in the surface layer (0-10 m) increasing gradually with depth across the nearfield transect, but only reaching concentrations >3 µM below 25 m at the stations further offshore (Figure 4-30). By mid September (WN01C), $NO_3$ levels were still depleted in the upper 5 m of surface waters along the transect, but concentrations had increased substantially below that depth. Although the physical oceanographic data suggest that stratification was weakening, there was no obvious indication of upwelling in the temperature and salinity data. It is unclear if the increase in nutrients was only due to increased mixing or if an upwelling event in early September may have been missed in the physical data, but captured in remnants of an elevated nutrient signature. A gradient in $NO_3$ concentrations was still associated with the pycnocline at 20 m. By early October (WN01D), biological utilization had reduced nutrient concentrations in the surface waters and $NO_3$ concentrations were <1 µM in the upper 15 m across the transect except for station N10 (1-3 µM) and there was a strong gradient in concentration associated with the pycnocline at 20 m. Temperature data had indicated that water column mixing had led to cooler surface and warmer bottom waters from mid September to early October, thus suggesting continued input of nutrients into the surface waters. A coincident increase in production (see Figure 5-2) over this time period, however, led to a decrease in nutrient concentrations.

By mid October (WF01E), $NO_3$ concentrations had once again increased to 1-5 µM throughout most of the surface layer (upper 20 m) and to >5 µM at depths below the weakening pycnocline (Figure 4-31). This was coincident with a decrease in production from the early October peak. Similar $NO_3$ concentrations were observed in late October. In early December (WN01G), $NO_3$ concentrations were relatively low (1-3 µM) in the upper 20 m at the inshore and offshore stations along the nearfield transect and there was still a gradient in nutrient concentrations associated with the weak pycnocline at the offshore stations. The availability of nutrients and the continued mild weather (relatively warm temperatures, few storm events, and as a result incomplete mixing) was coincident with the peak productivity at both stations N04 and N18 for this time period (see Section 5.1) and the highest chlorophyll concentrations of the fall/winter bloom. By late December, the water column was well mixed and nutrient concentrations had returned to typical winter levels over the entire nearfield transect.

An examination of the nutrient-nutrient plots showed that surface waters were generally depleted in DIN relative to $PO_4$ and $SiO_4$ in the nearfield during this semi-annual period (Appendix D).

### 4.2.2 Chlorophyll A

Chlorophyll concentrations (based on *in situ* fluorescence measurements) were relatively low for most of this time period, but reached unexpectedly high levels during the late fall/winter bloom in early December. Fall 2001 was a departure from the trend during the two previous years. During September and October of 1999 and 2000, substantial and prolonged fall blooms were observed, but in 2001 there was a minor fall bloom in September and with a more substantial bloom observed in late October and early December. The peak nearfield survey mean chlorophyll concentration was observed in early December, which is later in the season than usual and is the highest December mean observed since baseline monitoring began in 1992. Even with elevated chlorophyll concentrations in late October to December the fall nearfield mean areal chlorophyll value was about half (85 mg $m^{-2}$) that of the fall threshold value (161 mg $m^{-2}$), which continued the trend of relatively low chlorophyll concentrations that had been noted for the first half of 2001 (Libby *et al*., 2002).

#### 4.2.2.1 Horizontal Distribution

In July, nearfield surface chlorophyll concentrations were low and only reached concentrations of >1 $\mu gL^{-1}$ at the inshore stations. At mid-depth, concentrations were higher but variable across the nearfield with no clear trends (0.6 to 8.1 $\mu gL^{-1}$). Surface and mid-depth chlorophyll concentrations were both low in early August with surface concentrations of 1 $\mu gL^{-1}$ only measured at stations N10 and N11 and concentrations at the mid-depth 'chlorophyll max' ranging from a low of 0.6 $\mu gL^{-1}$ at N05 to a high of 2.7 $\mu gL^{-1}$ at station N10. By the late August nearfield/farfield combined survey, elevated surface chlorophyll concentrations 2-5 $\mu gL^{-1}$ were observed in Boston Harbor and the coastal and nearfield waters of western Massachusetts Bay (Figure 4-32a). The distribution was most closely tied to the distribution of DIN (specifically NH4; see Figure 4-20). The highest surface chlorophyll concentration was recorded at station N10 (5 $\mu g\ L^{-1}$). Surface chlorophyll concentrations were <1 $\mu gL^{-1}$ in the eastern nearfield and at boundary and Cape Cod Bay stations. Higher chlorophyll concentrations were observed at mid-depth with levels of 4-8 $\mu gL^{-1}$ measured in an area extending from the near harbor coastal and inshore nearfield stations to the south along the coast (Figure 4-32b). The high chlorophyll concentrations observed in both surface and mid-depth harbor and coastal waters were concomitant with high abundances of centric diatoms – *Leptocylindrus danicus*, *Skeletonema costatum*, and *Dactyliosolen fragilissimus* (see Figure 5-19). Phytoplankton abundances at other stations were comparable, but the assemblage was primarily comprised of microflagellates rather than centric diatoms.

There appeared to be little change from late August to mid September in nearfield surface and mid-depth chlorophyll concentrations, but SeaWiFS satellite imagery suggests that there was a relatively large increase (to 5-10 $\mu gL^{-1}$) in surface chlorophyll in early September (Figure 4-33). Although the sampling program did not capture this increase, the satellite images provided an indication of the short-term phytoplankton dynamics that occurred in early September of 2001. By mid September, surface water chlorophyll concentrations in the nearfield ranged from undetectable at station N15 to 2.5-3 $\mu gL^{-1}$ at stations N09 and N10. The trend of decreasing surface chlorophyll concentrations from southwest to northeast in the nearfield during WN01C were corroborated by similar trends in the concurrent SeaWiFS image that showed low concentrations in the northeastern portion of the nearfield (and Massachusetts Bay) and an increase in concentrations reaching 5-10 $\mu gL^{-1}$ to the south and inshore of the nearfield area (see Appendix I).

By the October combined nearfield/farfield survey (WF01E), high surface chlorophyll concentrations were observed at the coastal and southern Massachusetts Bay waters (Figure 4-34 ). SeaWiFS images indicated that chlorophyll concentrations had remained high (5-10 $\mu gL^{-1}$) in the coastal waters since the mid September survey (Appendix I). The October surface chlorophyll concentrations ranged from 0.9 $\mu gL^{-1}$ at station F29 to 10.5 $\mu gL^{-1}$ at station F18. The data were variable in northwestern Massachusetts Bay with the highest surface value measured at station F18 off of Nahant and chlorophyll concentrations of <2 $\mu\ L^{-1}$ in the northern nearfield, which is 5 km to the south. This sharp gradient of decreasing chlorophyll may have been an artifact of the sampling schedule. The nearfield stations were visited on October 20$^{th}$ and station F18 on October 25$^{th}$. Except for the elevated chlorophyll concentration at station F18, there was an increase in surface water chlorophyll concentrations from the northern nearfield across the nearfield and into southern Massachusetts Bay. Surface water chlorophyll concentrations of 4-7 $\mu gL^{-1}$ were measured along the southern edge of the nearfield, the Cohasset transect, and down to the stations along the Marshfield transect. Chlorophyll concentrations were relatively low (<2 $\mu gL^{-1}$) at most of the boundary and Cape Cod Bay stations. The chlorophyll maximum at most stations was in the upper water column and sampled at the mid-surface depth (Figure 4-34b). The pattern in chlorophyll concentrations at this depth was similar to that observed for the surface, although values were generally 1-2 $\mu gL^{-1}$ higher. The elevated surface and chlorophyll maximum concentrations were concomitant with higher nutrient concentrations in the upper water column in western Massachusetts Bay (see Figure 4-21).

Surface chlorophyll concentrations increased in the nearfield from October to early December. Surface concentrations ranged from a low of 3.5 $\mu gL^{-1}$ at station N21 to 8.2 $\mu gL^{-1}$ at station N16 and values were >6 $\mu gL^{-1}$ throughout the southeastern nearfield. These high chlorophyll concentrations in early December were coincident with an increase in diatoms (see Figures 5-17 and 5-18). SeaWiFS also measured elevated chlorophyll concentrations throughout the bays and the western Gulf of Maine in early December (Figure 4-35). Although no surveys were conducted in November, the limited number of SeaWiFS images available for that month suggest that elevated chlorophyll concentrations were present in the bays from late October to early December (see Appendix I). This late fall/early winter bloom achieved chlorophyll concentrations and production rates that are unprecedented in comparison to baseline values for December. By late December, surface chlorophyll concentrations had declined across the nearfield to values ranging from 0.5 $\mu gL^{-1}$ at station N17 to 2.7 $\mu gL^{-1}$ at station N01. The SeaWiFS image for this survey (December 19$^{th}$) was inferior, but the image for December 30$^{th}$ shows low surface chlorophyll concentrations throughout Massachusetts Bay (see Appendix I).

#### 4.2.2.2 Vertical Distribution

**Farfield.** Chlorophyll concentrations over the water column were examined along the three east/west farfield transects (Figure 1-3) to compare the vertical distribution of chlorophyll across the region. In August, the typical summer distribution of chlorophyll concentrations was observed along each of the transects with elevated concentrations in the surface waters at the inshore stations and near the pycnocline (15-20 m) further offshore. Overall the concentrations were relatively low with values reaching 3-6 $\mu g\ L^{-1}$ at the near surface and near pycnocline chlorophyll maxima as shown for the Boston-Nearfield transect (Figure 4-36a). A subsurface layer of high chlorophyll concentrations was measured along the Nearfield-Marshfield transect with the highest values measured at station F10 (Figure 4-36b). The chlorophyll patterns illustrated along these two transects appear to be related to those shown in Figure 4-27 for $NH_4$ concentrations. The availability of $NH_4$, which is preferentially taken up by phytoplankton over $NO_3$, may have contributed to the elevated chlorophyll concentrations along the Nearfield-Marshfield transect. The physical and biological dynamics associated with the distribution of nutrients and chlorophyll are complex and it may not be possible to clearly distinguish between the influence of background nutrients and effluent $NH_4$. This will be examined in more detail in the 2001 annual water column report.

By October (WF01E), chlorophyll concentrations along each of transects were slightly higher than those measured in August and high concentrations were measured over a relatively thick layer extending from the surface to the pycnocline at 15-20 m (Figure 4-37). Along the Boston-Nearfield transect, chlorophyll concentrations were 3-5 $\mu g\ L^{-1}$ in the surface and near surface chlorophyll maximum except at harbor station F23. Higher concentrations were observed in the surface and subsurface maximum (>5 $\mu g\ L^{-1}$) along the two transects to the south. The higher concentration at station F06 along the Marshfield transect was coincident with the highest phytoplankton abundance for the October survey. The increase in chlorophyll concentrations along these transects may have been related to the increase in nutrient availability in October compared to August.

**Nearfield.** Trends in the nearfield chlorophyll concentrations are summarized in Figure 4-38. This figure presents the average of the surface, mid-depth, and bottom values for each nearfield survey.

Note that when a subsurface chlorophyll maximum was present, the mid-depth sample represents the water quality characteristics associated with the feature. The nearfield mean for the mid-depth chlorophyll concentrations was higher than the surface and bottom mean values for all but one of the surveys during this time period. In July and August, surface and bottom water nearfield chlorophyll concentrations were consistently low (≤1 $\mu gL^{-1}$; Figure 4-38). At mid-depth, the survey mean chlorophyll concentration decreased from 5 $\mu gL^{-1}$ in early July to almost 1 $\mu gL^{-1}$ in early August and then returned to 4 $\mu gL^{-1}$ by the late August survey. These relatively high chlorophyll concentrations (4 $\mu gL^{-1}$) continued to be observed in the nearfield at mid-depth from late August to early October and after a decline in concentrations in mid-October mean concentrations increased to 5 and 7 $\mu gL^{-1}$ during the late October and early December surveys, respectively. There was a steady increase in surface chlorophyll concentrations from 1 $\mu gL^{-1}$ in late August to a maximum of >5 $\mu gL^{-1}$ in early December. The elevated chlorophyll concentrations in October and December were coincident with peaks in primary production.

The vertical distribution of chlorophyll during the late fall bloom was examined in more detail along a transect extending diagonally through the nearfield from the southwest to the northeast corner (see Figure 1-3). The southwest corner, station N10, often exhibits an inshore or harbor chlorophyll signal while an offshore chlorophyll signal is more often observed at the northeast corner, station N04. In September, chlorophyll concentrations were low (<1 $\mu gL^{-1}$) in the surface waters and reached a maximum in a narrow subsurface layer at all but harbor-influenced station N10 (3-5 $\mu gL^{-1}$; Figure 4-39). By early October, the range in chlorophyll concentrations had increased only slightly, but elevated concentrations were measured over a thick layer from 5-25 m. A similar pattern was observed during both subsequent surveys in October (Figures 4-39 and 4-40). During the October surveys, elevated chlorophyll concentrations were generally measured over the entire upper 15-20 m of the water column at the inshore stations N10 and N19, while low surface and subsurface chlorophyll maximum concentrations were observed further from shore. This pattern of a surface chlorophyll maximum inshore and a separate subsurface chlorophyll maximum further offshore has been noted during previous fall blooms. By early December, chlorophyll concentrations had increased to 4-12 $\mu gL^{-1}$ in the upper 25-30 m over nearly the entire transect (Figure 4-40). The high chlorophyll concentrations were coincident with the peak production rates for this July to December period and with high abundances of diatoms. By late December, chlorophyll concentrations along the nearfield transect had returned to more typical winter levels.

The progression of chlorophyll concentrations in the nearfield during the fall of 2001 can be more clearly seen through a series of contour plots of fluorescence over time at stations N10, N18, and N07 (Figure 4-41). These stations are representative of inshore (N10), center (N18), and offshore (N07) nearfield stations. The late fall/early winter bloom clearly stands out in the chlorophyll concentration contours at each of these stations. At station N10, chlorophyll concentrations in the upper 10-15 m ranged were generally 2-5 $\mu gL^{-1}$ from July to late October. At stations N07 and N18, a subsurface chlorophyll maximum of 2-5 $\mu gL^{-1}$ was measured in July and then again in September and October, but not during the August surveys. Chlorophyll concentrations peaked in early December at each of these stations and extended over the entire water column (30 m) at station N10 and N18 and to a depth of 25 m at station N07. These contours suggest that there was a prolonged bloom from October to December, and ancillary data (SeaWiFS imagery) imply that this was the case. Mooring data for chlorophyll fluorescence are currently available through October 23rd, but the full 2001 dataset will be available for inclusion in the annual report and will provide additional insight into the duration and magnitude of the atypical late fall/early winter bloom of 2001.

### 4.2.3 Dissolved Oxygen

Spatial and temporal trends in the concentration of dissolved oxygen (DO) were evaluated for the entire region (Section 4.2.3.1) and for the nearfield area (Section 4.2.3.2). Due to the importance of identifying low DO conditions, bottom water DO minima were examined for the water sampling events. The minimum bottom water DO concentration was 7.0 $mgL^{-1}$ in the nearfield at station N13 during in late October (WN01F) and stations N01 and N16 in early December (WN01G). Regionally, a DO concentration minimum of 7.2 $mgL^{-1}$ was observed at coastal station F14 in October. Not surprisingly, the lowest %saturation value for the year in the nearfield (73%) was measured at stations N13 (WN01F) and N16 (WN01G). The lowest farfield %saturation value was 75% measured at station F16 in October.

The 2001 nearfield survey mean bottom water DO minimum of 7.4 $mgL^{-1}$ was measured during the mid and late October surveys. The survey mean bottom water DO %saturation minimum (77%) occurred during the mid October survey and only slightly higher at 78% in late October. These values were comparable to the survey mean bottom water minima for Stellwagen Basin stations – 7.8 $mgL^{-1}$ and 79%. Although all of these survey mean minimum values were relatively high, the DO %saturation values were below the caution threshold (80%) for both the nearfield and Stellwagen Basin, but well above the background values calculated based on the baseline data (64.3% and 66.3%, respectively).

The bottom water DO survey minimum values were relatively high and comparable to those measured in the fall of 2000. It might be expected that 2001 DO values would be high given the relatively low chlorophyll concentrations measured in 2001 and presumed low level of organic loading to the bottom waters and benthos. The fact that similar DO minima were observed in two very different 'biological' years – major spring and fall blooms in 2000 and minor blooms in 2001 – suggests that either loading plays a relatively minor role in controlling bottom water DO or that the presumption that high chlorophyll concentrations are indicative of high loading is incorrect. An examination of the connection between physical oceanographic conditions and DO concentrations suggests that it is the former (Geyer *et al*., 2002).

#### 4.2.3.1 Regional Trends of Dissolved Oxygen

Temporal trends in bottom water DO concentrations were limited for the farfield as stations were only sampled twice during this period and due to technical problems the *in situ* sensor data from WF01B (and WN01A) were marked suspect. DO concentrations from Winkler analyses (bottle data) are presented for WF01B. Survey mean DO concentrations reached minimum values in October for each of the farfield areas – 7.5-7.6 $mgL^{-1}$ in the coastal and offshore areas and 7.9-8.1 $mgL^{-1}$ in Boston Harbor, boundary, and Cape Cod Bay waters. A comparison of bottom water bottle data showed a 1 $mgL^{-1}$ decrease in DO concentrations from August to October in each of the areas. The mean DO %saturation at these areas also reached a minimum in October and ranged from a low of 79% for the offshore area to a high of 90% in Boston Harbor and Cape Cod Bay. Overall, as in the nearfield, bottom water DO concentrations and %saturation were relatively high in the farfield areas.

In August (WF01B), bottom water DO concentrations were high throughout the bays ranging from a minimum of 8.6 mg $L^{-1}$ at station F26 of off Cape Ann to a maximum of 9.8 mg $L^{-1}$ at station N07 in the nearfield (Figure 4-42). By October (WF01E), bottom water DO concentrations had decreased by 0.5-2 mg $L^{-1}$ across the bays (Figure 4-43). The lowest DO concentration was measured at coastal station F24 (7.4 mg $L^{-1}$) and the highest at station F29 off of Provincetown (8.6 mg $L^{-1}$). In addition to the low DO concentration at station F24, bottom water concentrations in the nearfield and much of the eastern half of Massachusetts Bay were approximately 7.5 m mg $L^{-1}$. A more detailed picture of the DO distribution in bottom waters is presented in Figure 4-44 that shows the DO concentrations measured *in situ*. These data indicate that DO concentrations of 7.2 to 7.5 mg $L^{-1}$ were observed in the coastal and nearfield waters and concentrations increased both offshore and to the south. Bottom water temperatures were warmer at these shallower inshore stations and chlorophyll concentrations were consistently elevated compared to further offshore.

#### 4.2.3.2 Nearfield Trends of Dissolved Oxygen

Dissolved oxygen concentrations and percent saturation values for both the surface and bottom waters at the nearfield stations were averaged and plotted for each of the nearfield surveys (Figure 4-45). The gradient in mean DO concentration between the surface and bottom waters ranged from 0.2 to 2.2 $mgL^{-1}$ over this time period. During the summer, lower production rates and higher respiration rates (see Section 5.2) led to decreases in mean DO concentrations from July to mid September of 1 $mgL^{-1}$ in the surface waters and almost 2 $mgL^{-1}$ for the bottom waters. Mean DO concentrations remained steady from September to early October as both production and respiration rates increased over this time period. The nearfield bottom water survey mean DO concentration minimum (7.4 $mgL^{-1}$) was observed during the second and third surveys in October, which were conducted 9 days apart (October 20$^{th}$ and 29$^{th}$). The relatively mild fall and early winter that led to weak mixing and a late fall bloom also contributed to an extended period of relatively low DO. The mean bottom water DO concentration increased slightly from late October (7.4 $mgL^{-1}$) to early December (7.7 $mgL^{-1}$). By late December, the water column had finally become well mixed across the entire nearfield and mean surface and bottom water DO concentrations were 9.5 $mgL^{-1}$.

DO %saturation followed a trend similar to that of DO concentration (Figure 4-45b). The differences are due to the dependent relationship between temperature and DO %saturation, the large gradient in temperature between surface and bottom waters in the summer, and the eventual decrease of the temperature gradient in the fall as the surface waters cool and bottom waters warm. From early July to early December, there was a 20-30% difference in %saturation between surface and bottom waters. The surface waters were above 100% saturation for the entire July to December period, while bottom waters were under saturated for all but the late December surveys. From mid September to early December, survey mean bottom water DO %saturation was about 80% and reached a minimum of 77% in mid October. The duration of these conditions was due to the weak mixing that occurred in fall 2001.

## 4.3 Contingency Plan Thresholds

September 6, 2000 marked the end of the baseline period, completing the data set for MWRA to calculate the threshold values used to compare monitoring results to baseline conditions. Those parameters include background levels for water quality parameters chlorophyll and dissolved oxygen. Annual and seasonal chlorophyll areal concentration thresholds have been developed for the nearfield area and bottom water dissolved oxygen concentration and percent saturation minima thresholds have been designated for the nearfield and Stellwagen Basin (Table 4-1). There were no threshold exceedances for water quality parameters in 2001.

For the second half of 2001, the summer and fall 2001 seasonal nearfield areal means were low 45 and 85 mg $m^{-2}$ respectively, which is almost half the caution threshold value. These low seasonal values in combination with the low winter/spring 2001 mean resulted in an annual areal chlorophyll mean of 67 mg $m^{-2}$ well below the caution threshold of 107 mg $m^{-2}$ (Table 4-1). The dissolved oxygen concentration survey mean minimum for the fall of 2001 was well above the threshold standard for both the nearfield and Stellwagen Basin. The percent saturation values were slightly below the caution threshold of 80% in each area, but the survey mean minima that were measured were well above the background value and thus no threshold exceedance.

**Table 4-1. Contingency plan threshold values for water quality parameters.**

| Parameter | Time Period | Caution Level | Warning Level | Background | 2001 |
|---|---|---|---|---|---|
| Bottom Water DO concentration | Survey Mean in June-October | < 6.5 mg/l (unless background lower) | < 6.0 mg/l (unless background lower) | Nearfield - 5.75 mg/l<br>Stellwagen - 6.2 mg/l | 7.4 mg/L<br>7.8 mg/L |
| Bottom Water DO %saturation | Survey Mean in June-October | < 80% (unless background lower) | < 75% (unless background lower) | Nearfield - 64.3%<br>Stellwagen - 66.3% | 77%<br>79% |
| Chlorophyll | Annual | 107 mg/m$^2$ | 143 mg/m$^2$ | -- | 67 mg/m$^2$ |
| | Winter/spring | 182 mg/m$^2$ | -- | -- | 69 mg/m$^2$ |
| | Summer | 80 mg/m$^2$ | -- | -- | 45 mg/m$^2$ |
| | Autumn | 161 mg/m$^2$ | -- | -- | 85 mg/m$^2$ |

## 4.4 Summary of Water Column Results

### Summary of Water Column Results

- Regionally, seasonal stratification had deteriorated at the inshore stations and began to weaken at the offshore stations by the October survey (WF01E).
- In the nearfield, stratification had weakened by early October (WN01D), but a weak density gradient existed through to early December (WN01G). Well-mixed winter conditions were not achieved until late December (WN01H).
- The mild fall weather likely led to the weak mixing conditions and the extended duration of weakly stratified conditions.
- Nutrient concentrations followed typical trends during the 2001 July to December. Depleted concentrations in the surface waters during summer stratified conditions, increasing concentrations with the breakdown of stratification and increase in mixing, punctuated with decreases due to biological utilization during the fall bloom, and finally return to typical winter levels.
- $NH_4$ concentrations continue to be a good tracer, albeit not a conservative tracer, of the effluent plume both within and extending from the nearfield. In August, a layer of lower salinity and higher $NH_4$ concentrations (plume signature) extended from the nearfield into southern Massachusetts Bay.
- Chlorophyll concentrations were relatively low for most of this time period, but reached unexpectedly high levels during the late fall/winter bloom in early December.
- Fall 2001 was a departure from 1999 and 2000 when large and prolonged fall blooms were observed. In 2001 there was a minor fall bloom in September and then a more substantial bloom from October to early December.
- The highest nearfield survey mean chlorophyll concentration was observed in early December, which is later in the season than usual and was the highest December mean observed since baseline monitoring began in 1992.
- The summer, fall, and annual mean areal chlorophyll threshold values were well below the cautions levels – by about 50%.

- Mean nearfield bottom water DO concentrations in 2001 were relatively high and well above the caution thresholds.
- DO percent saturation values in October fell just below the caution threshold (<80%) in both the nearfield and Stellwagen Basin (77% and 79%, respectively). The DO percent saturations in both of these areas were well above baseline background levels (64.3% and 66.3%, respectively).

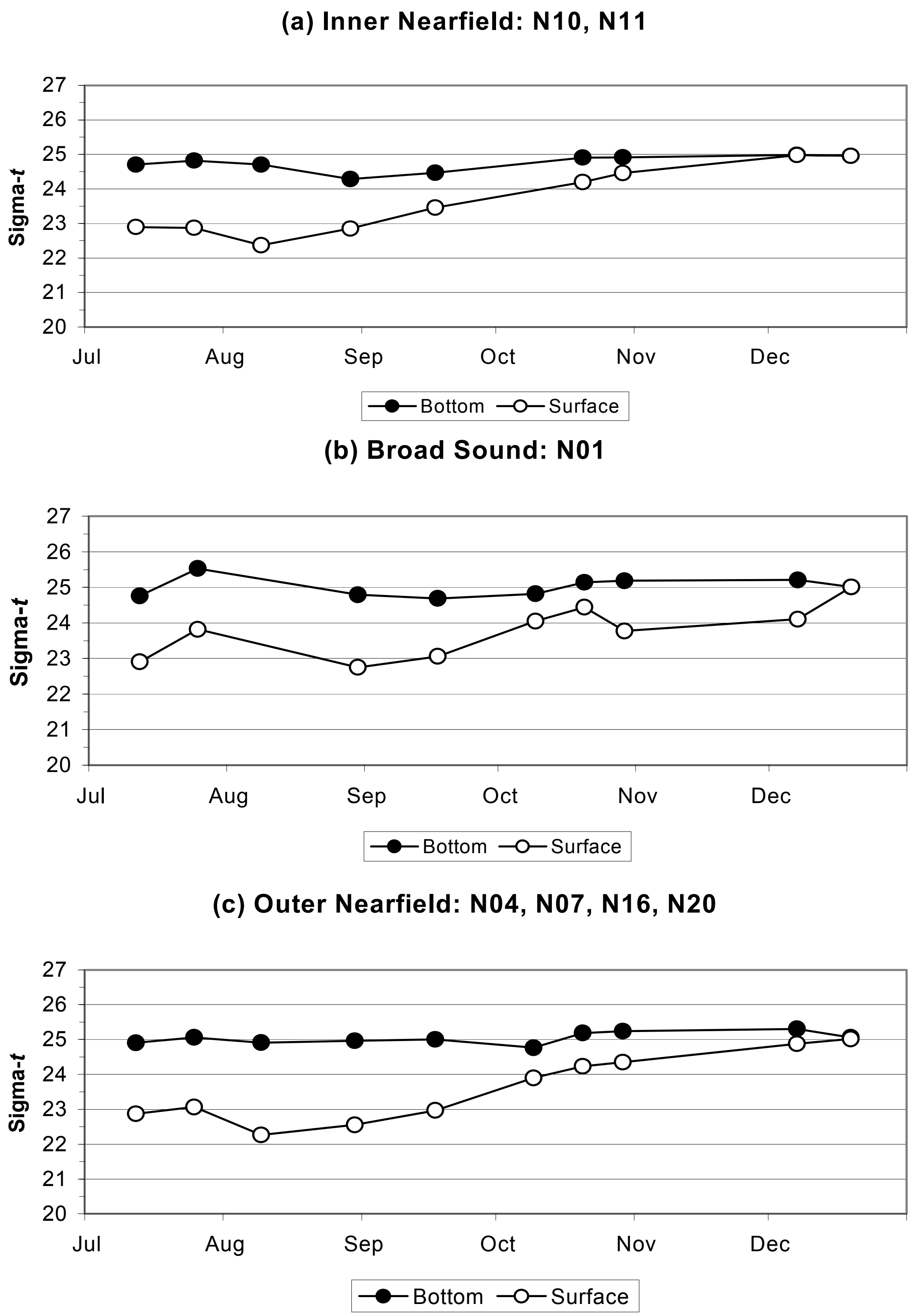



**Figure 4-1. Time-Series of Average Surface and Bottom Water Density ($\sigma_T$) in the Nearfield**

Note: No data are available for survey WN01A (station N01) and WN01D (stations N10 and N11)

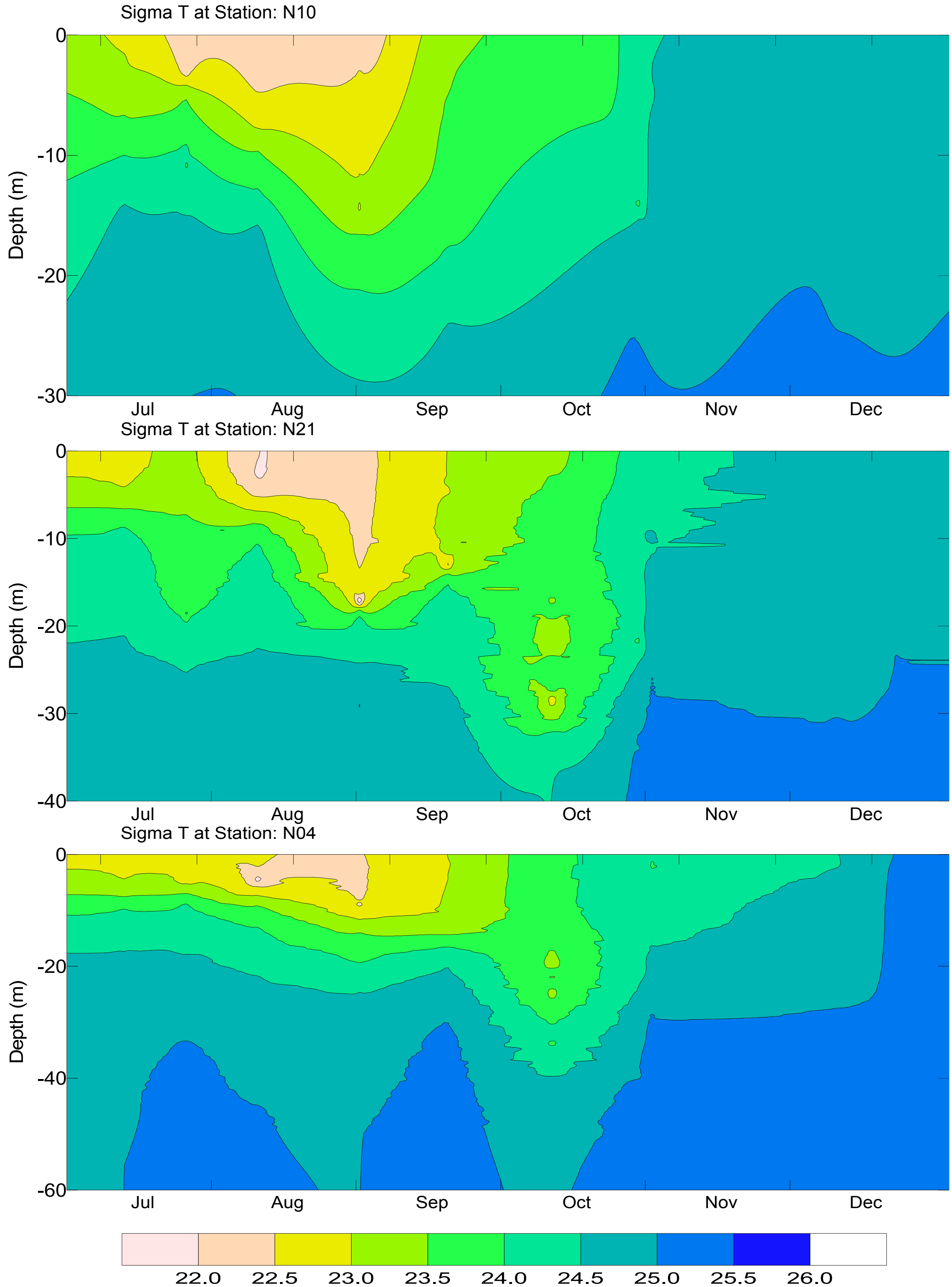



**Figure 4-2. Sigma-*t* Depth vs. Time Contour Profiles for Stations N10, N21, and N04**

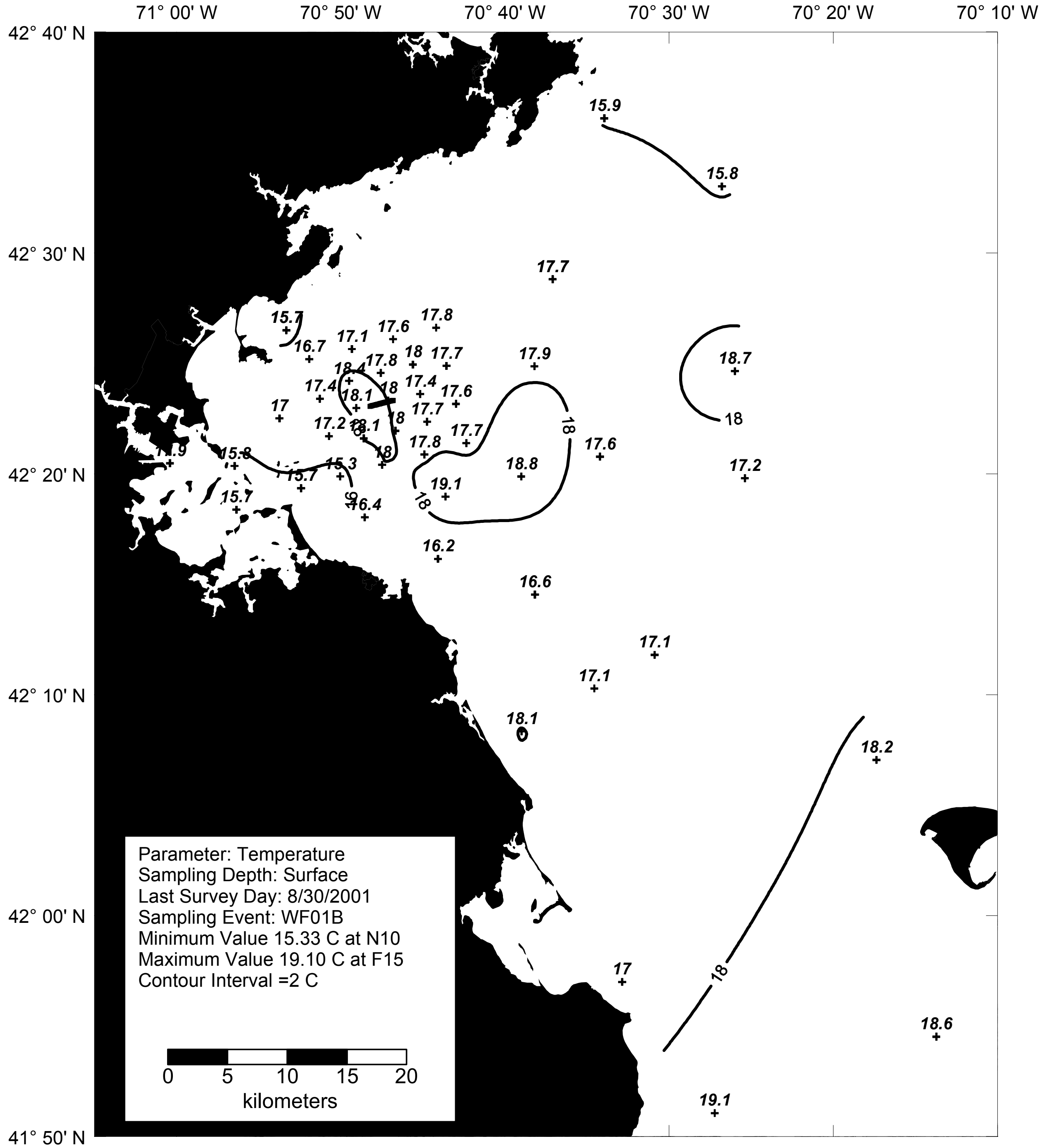



**Figure 4-3. Temperature Surface Contour Plot for Farfield Survey WF01B (Aug 01)**

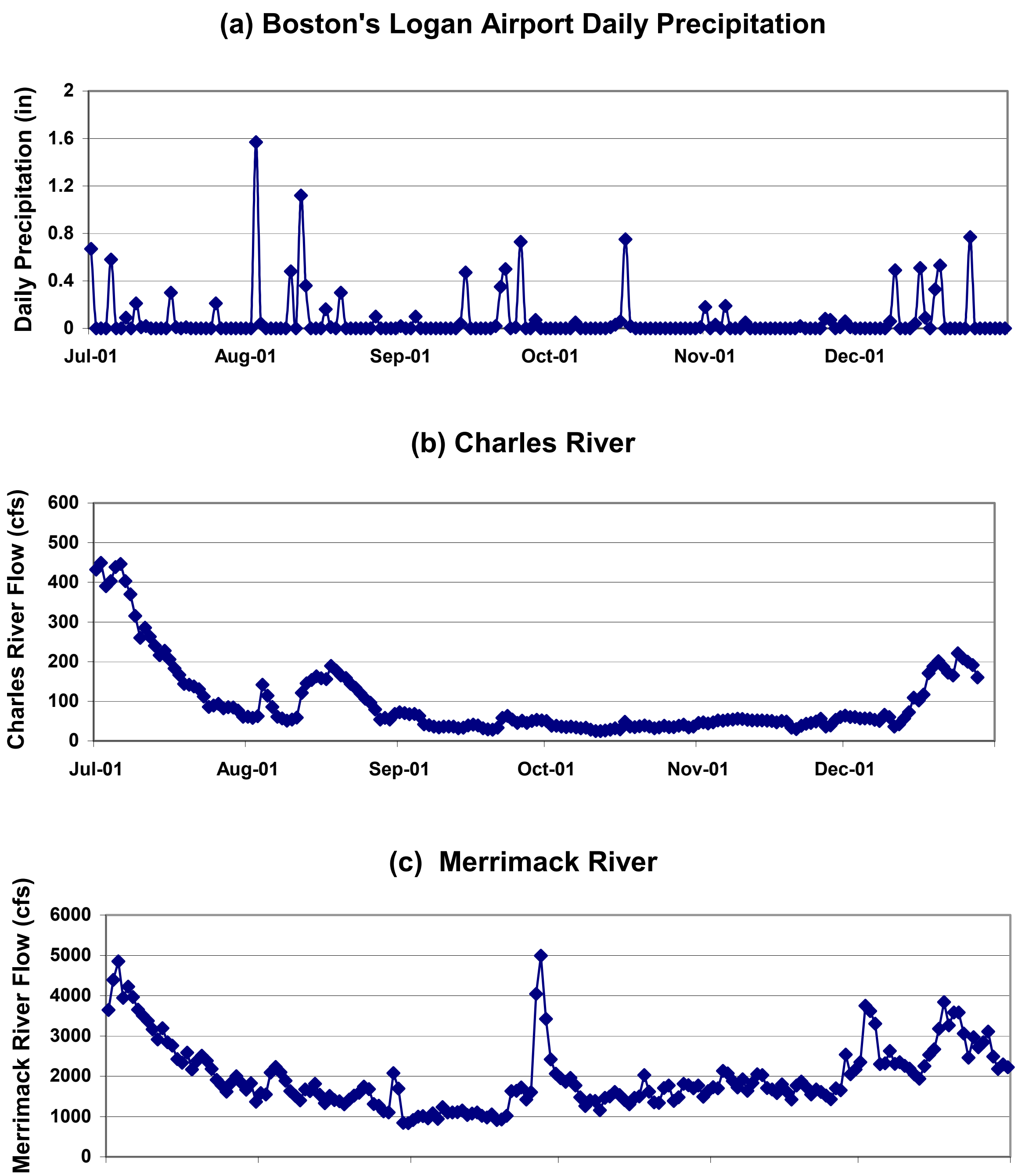



**Figure 4-4. Precipitation at Logan Airport and River Discharges for the Charles and Merrimack Rivers**

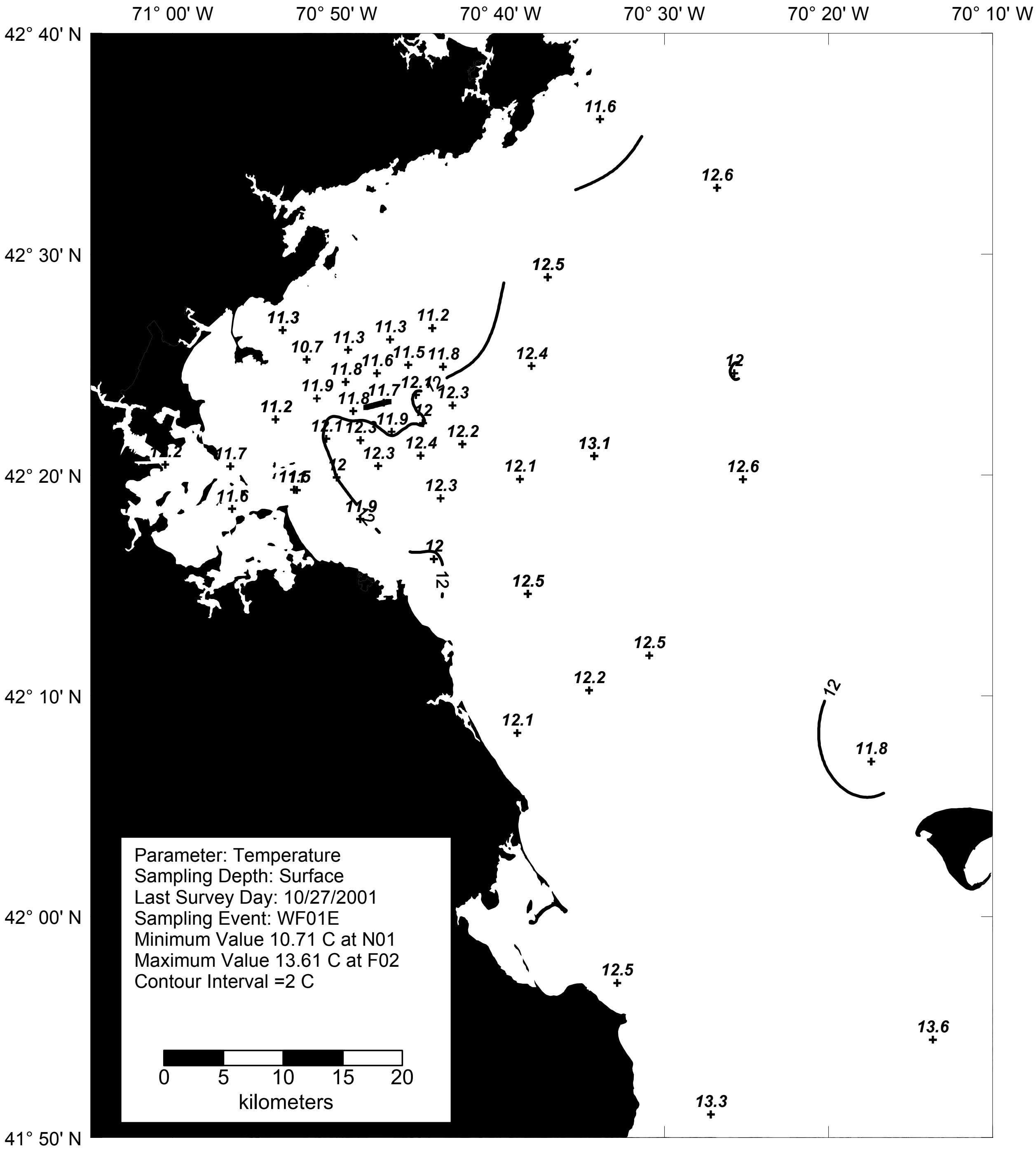



**Figure 4-5. Temperature Surface Contour Plot for Farfield Survey WF01E (Oct 01)**

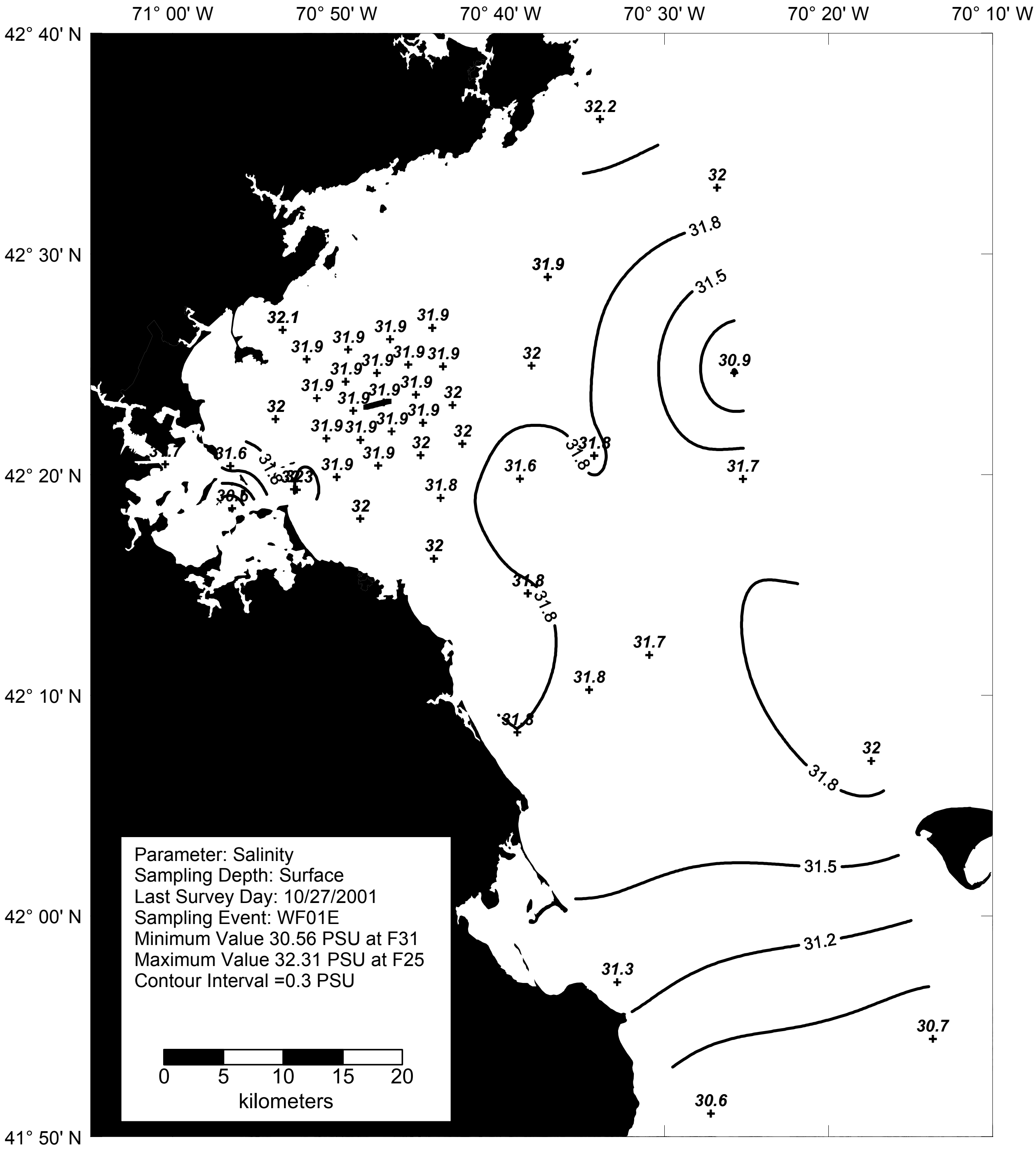



**Figure 4-6. Salinity Surface Contour Plot for Farfield Survey WF01E (Oct 01)**

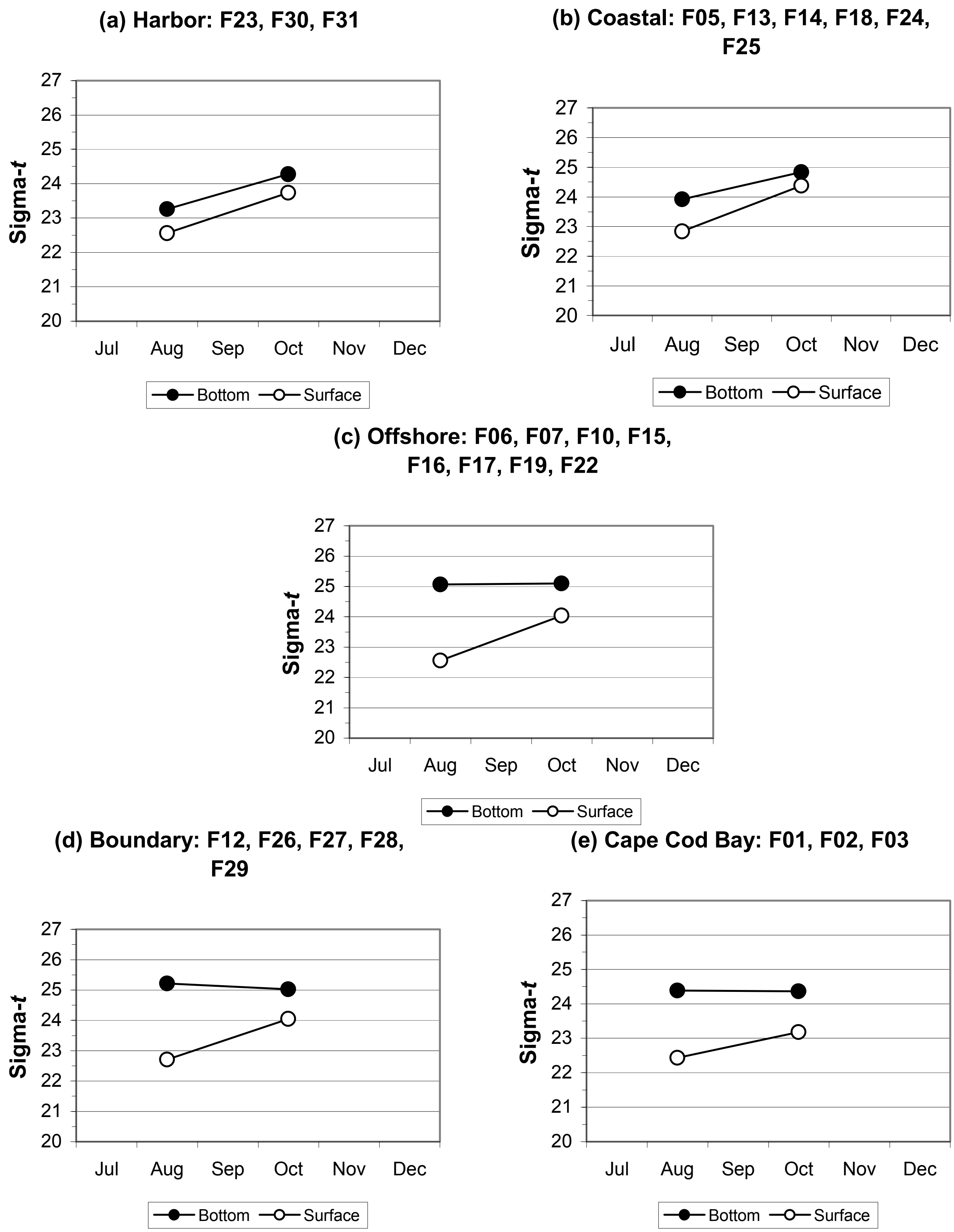



**Figure 4-7. Time-Series of Average Surface and Bottom Water Density ($\sigma_T$) in the Farfield**

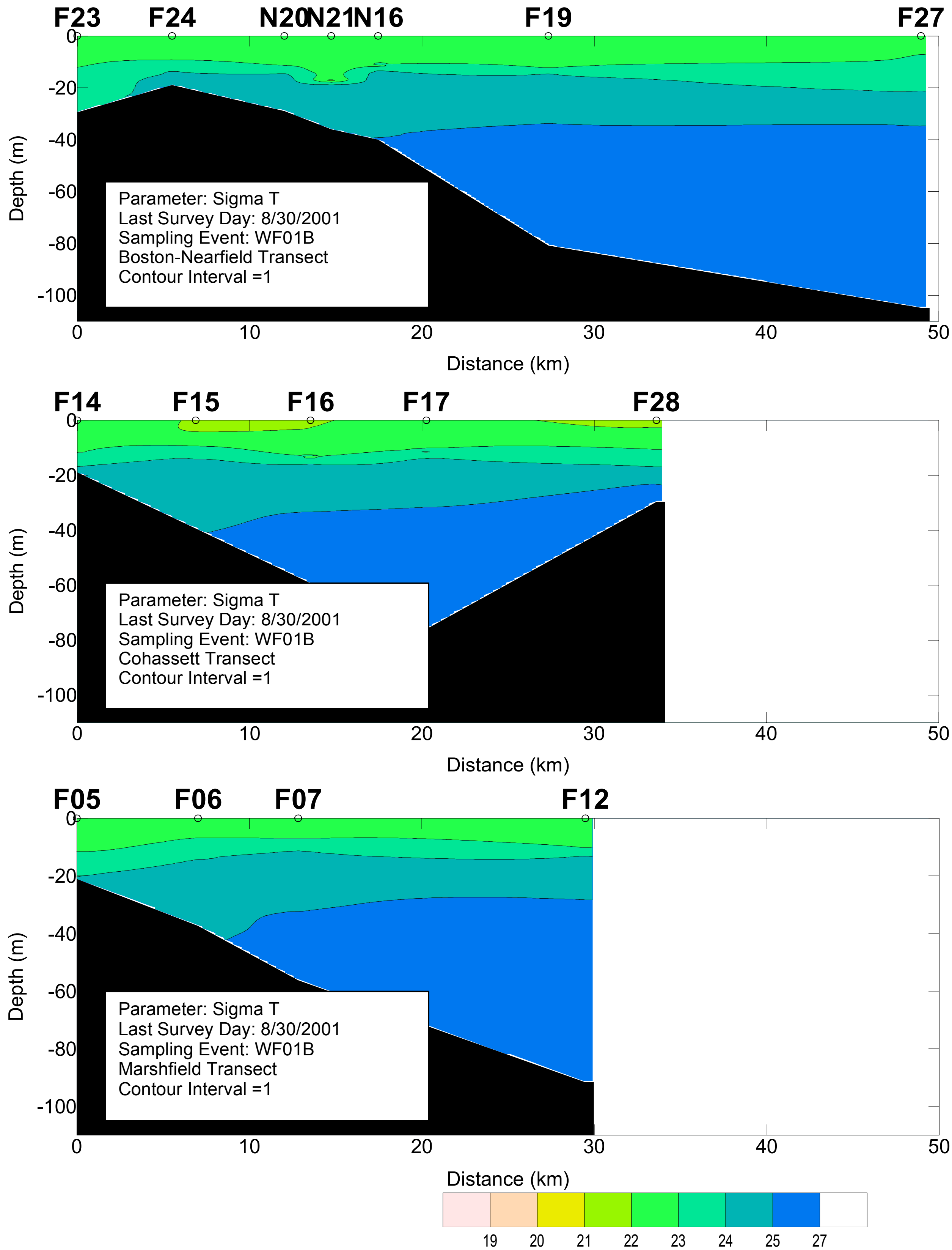



**Figure 4-8. Sigma-*t* Vertical Transects for Farfield Survey WF01B (Aug 01)**

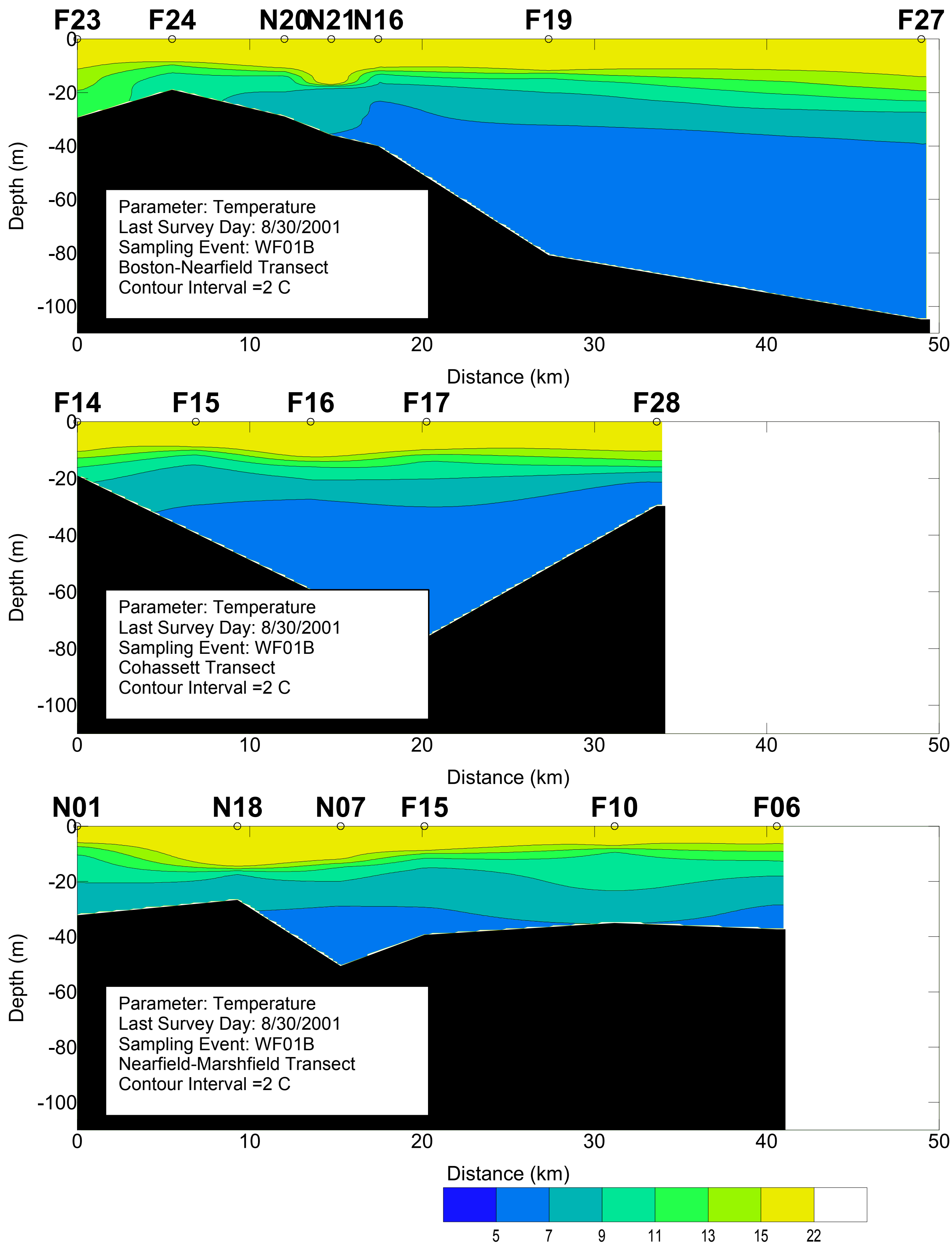



**Figure 4-9. Temperature Vertical Transect for Farfield Survey WF01B (Aug 01)**

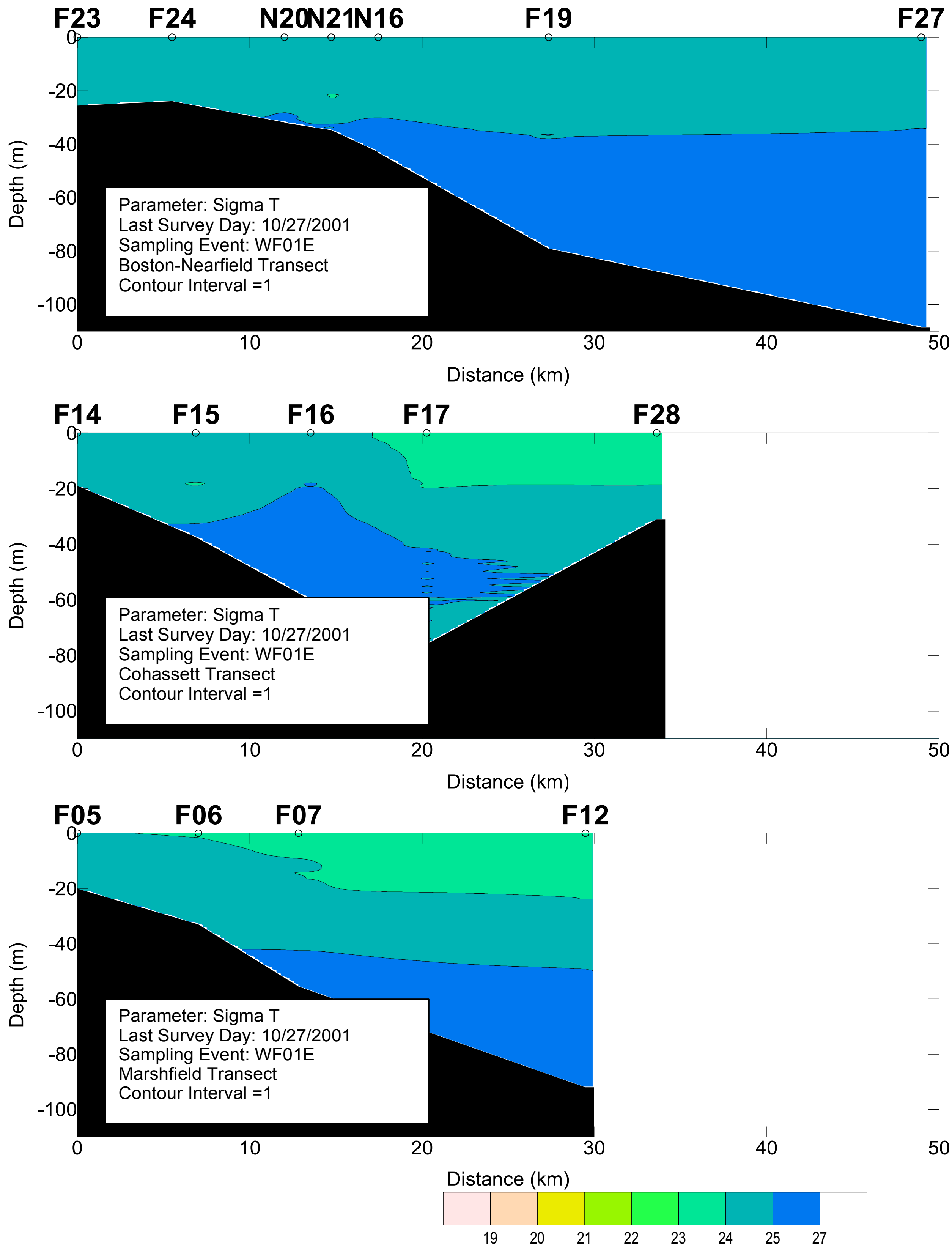
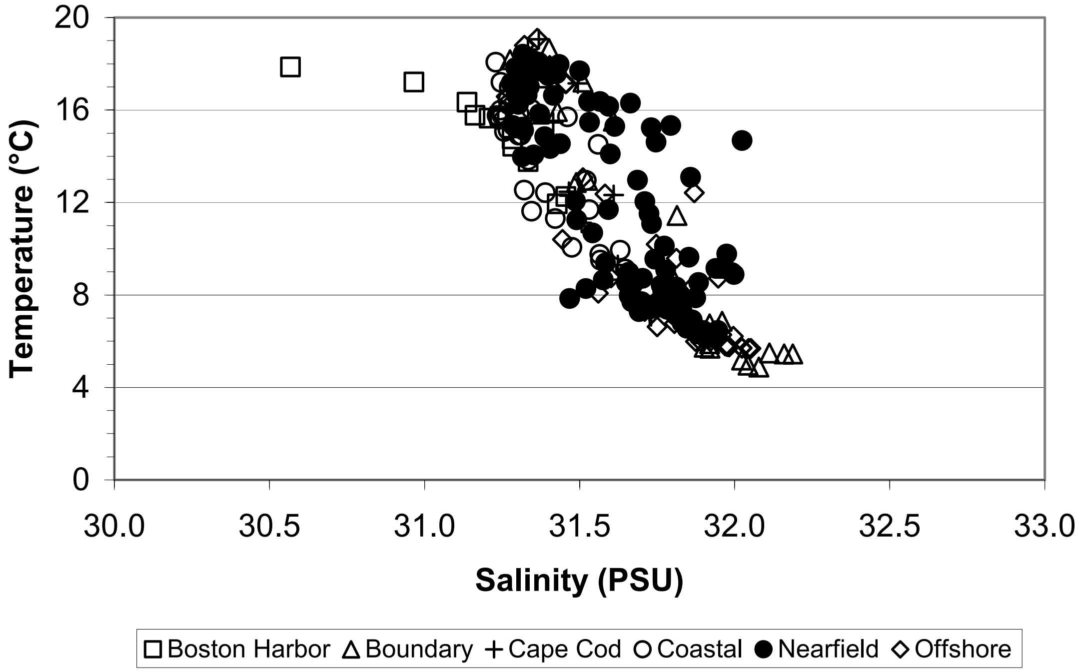



**Figure 4-10. Sigma-*t* Vertical Transect for Farfield Survey WF01E (Oct 01)**

**(a) WF01B: August**




**(b) WF01E: October**

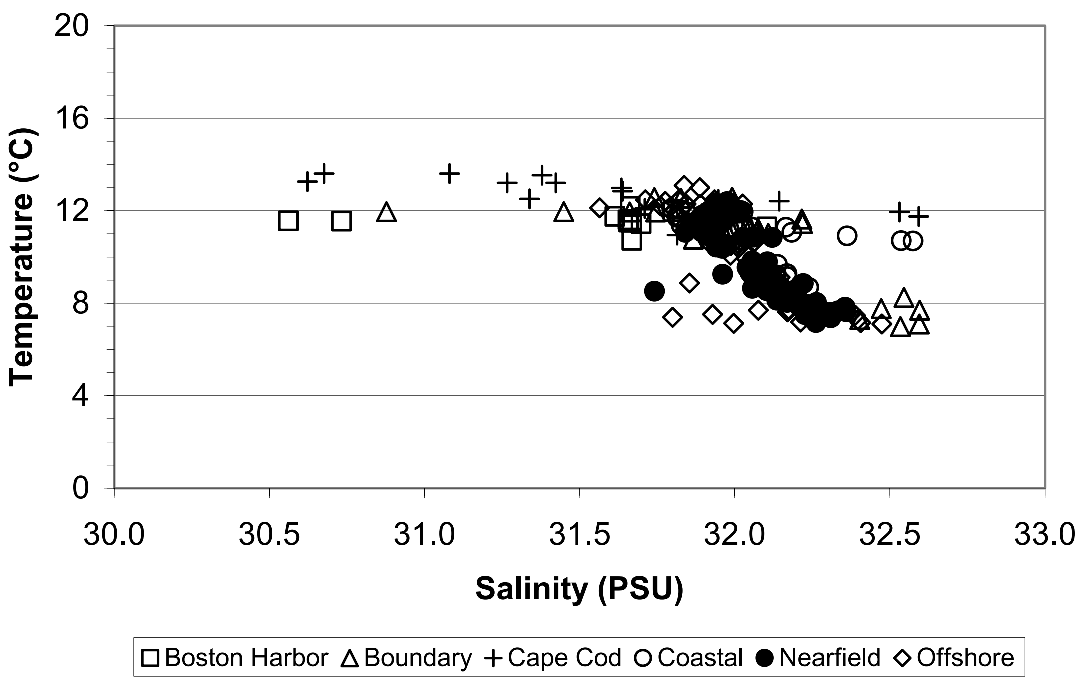



**Figure 4-11. Temperature/Salinity Distribution for All Depths during (a) August and (b) October**

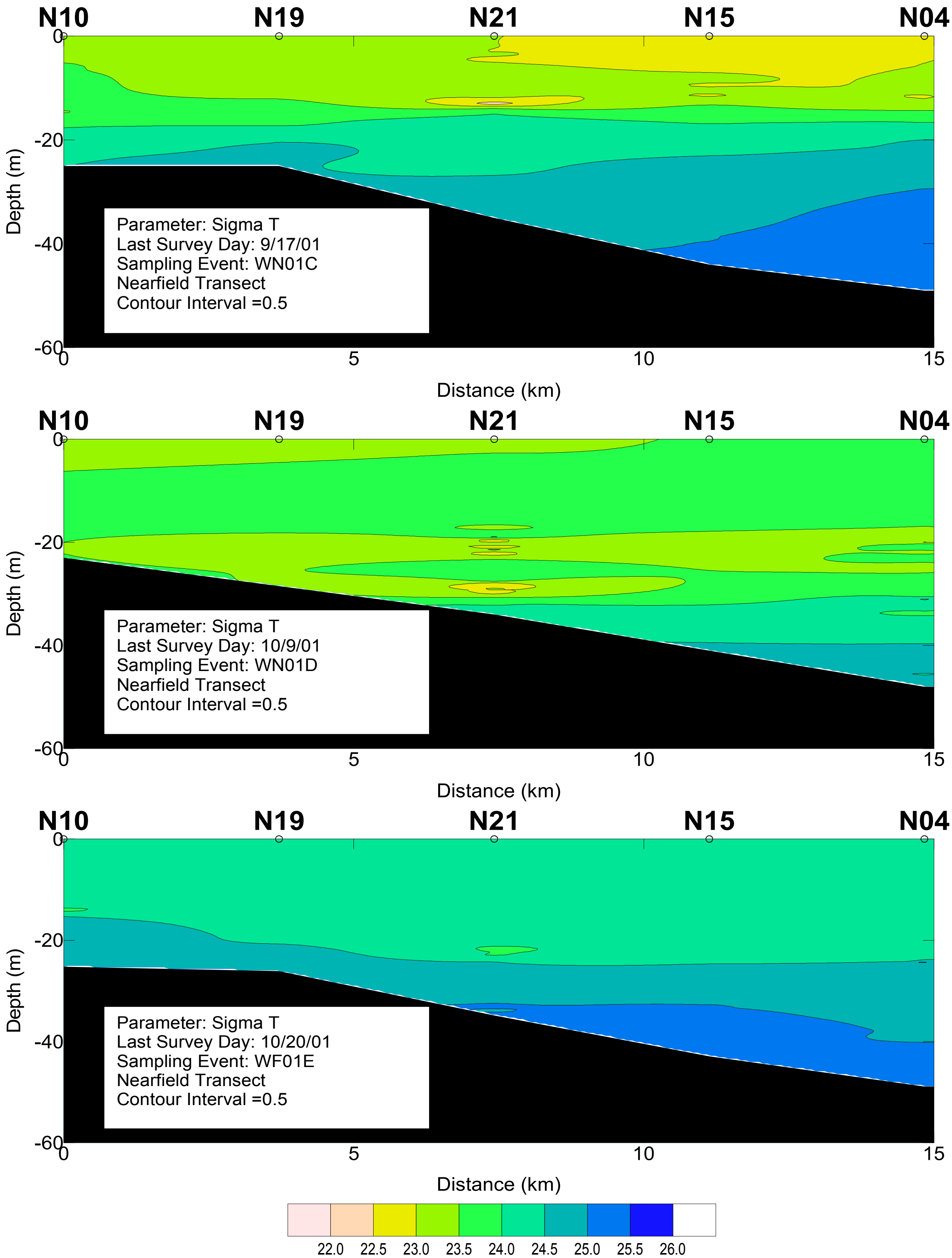



**Figure 4-12. Sigma-*t* Vertical Nearfield Transect for Surveys WN01C, WN01D, and WF01E**

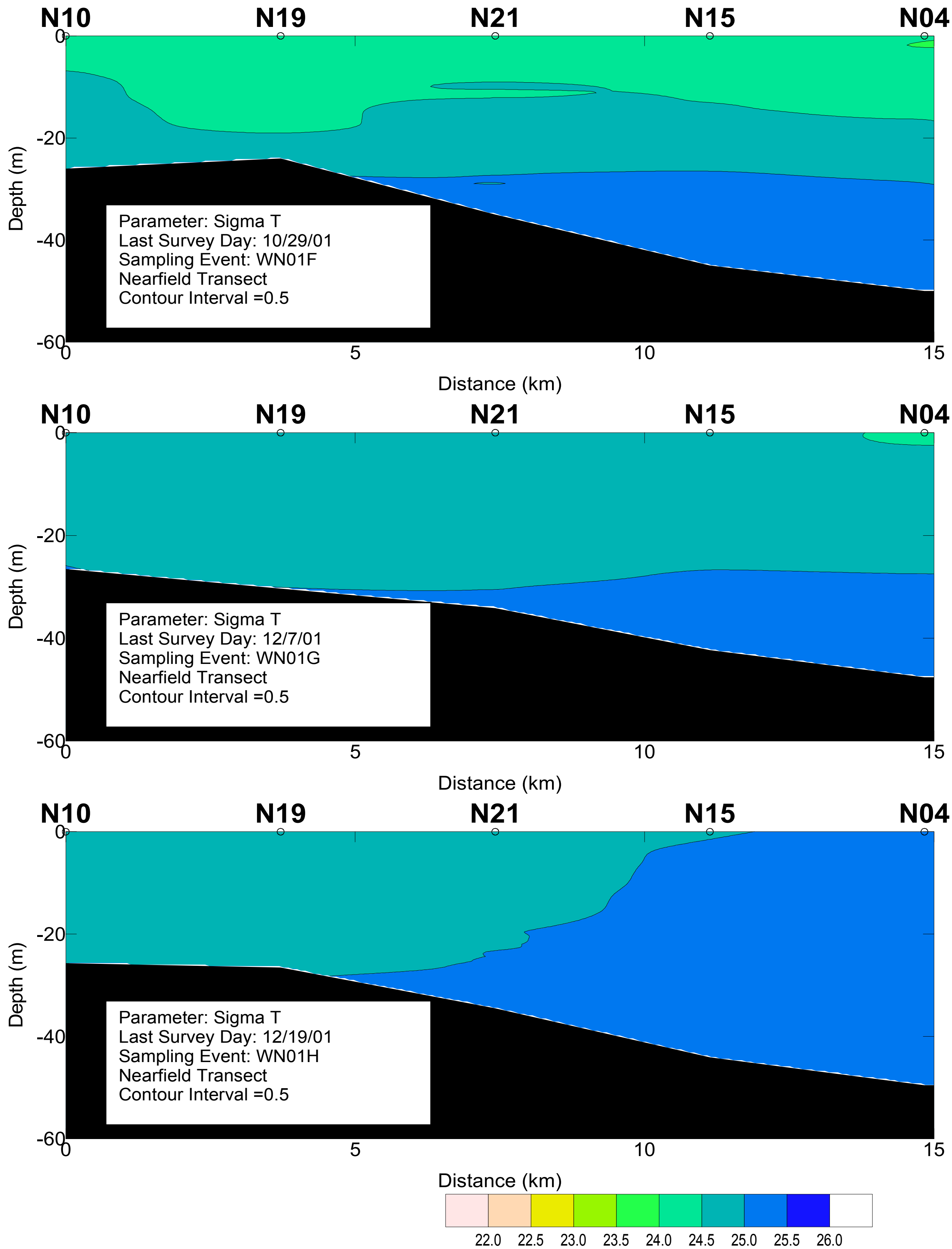



**Figure 4-13. Sigma-*t* Vertical Nearfield Transect for Surveys WN01F, WN01G, and WN01H**

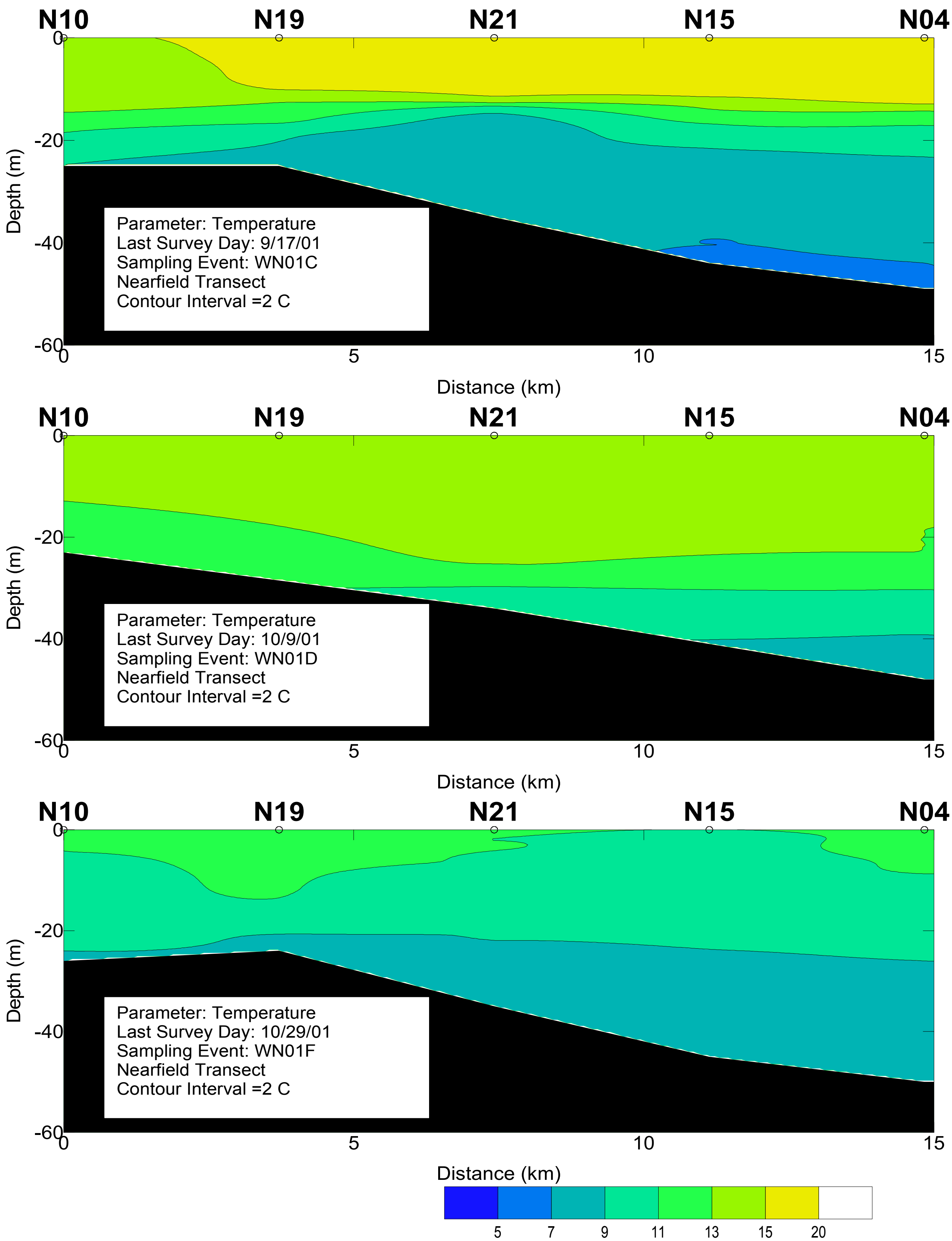



**Figure 4-14. Temperature Vertical Nearfield Transect for Surveys WN01C, WN01D, and WN01F**

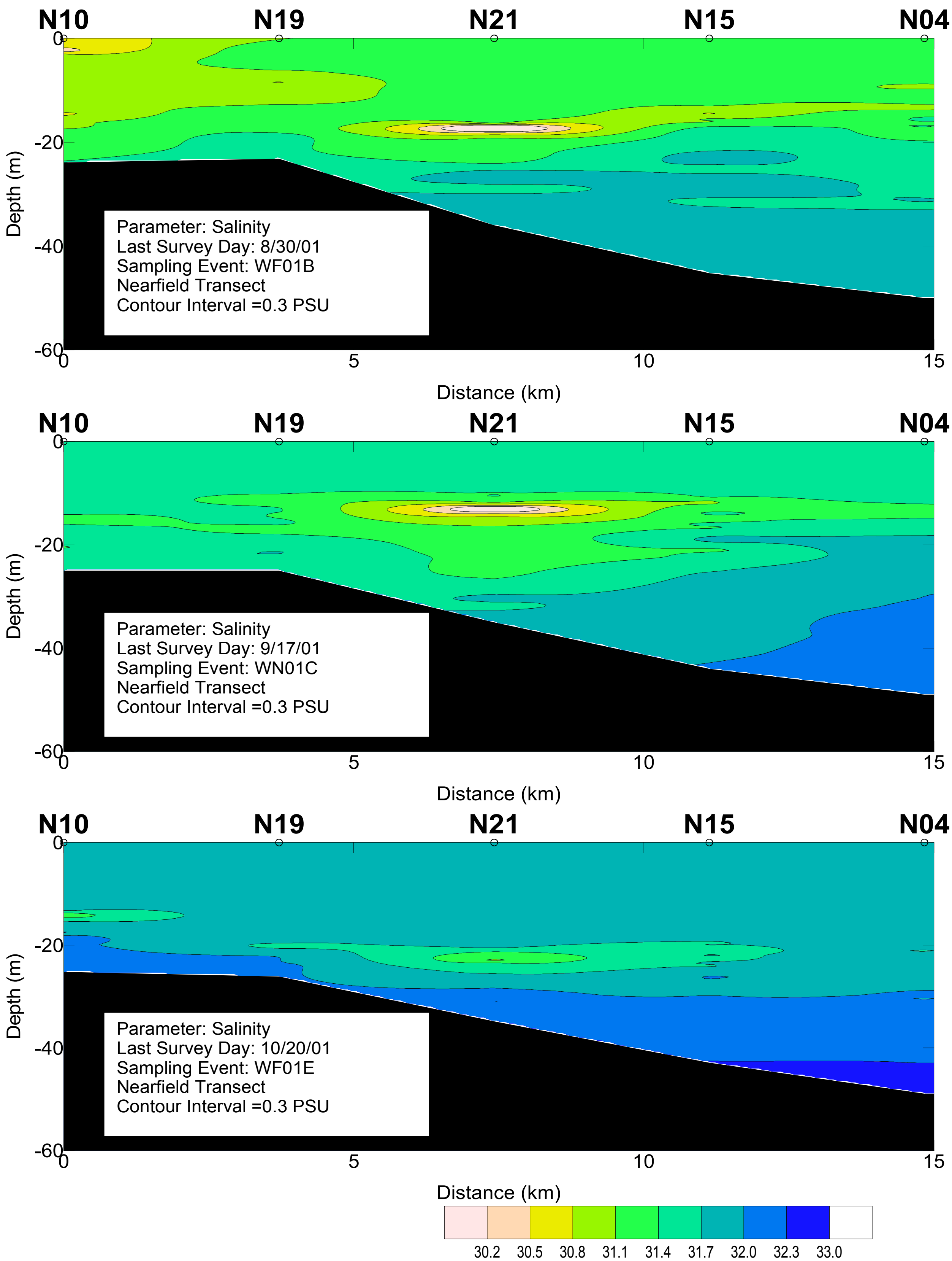



**Figure 4-15. Salinity Vertical Nearfield Transect for Surveys WF01B, WN01C, and WF01E**

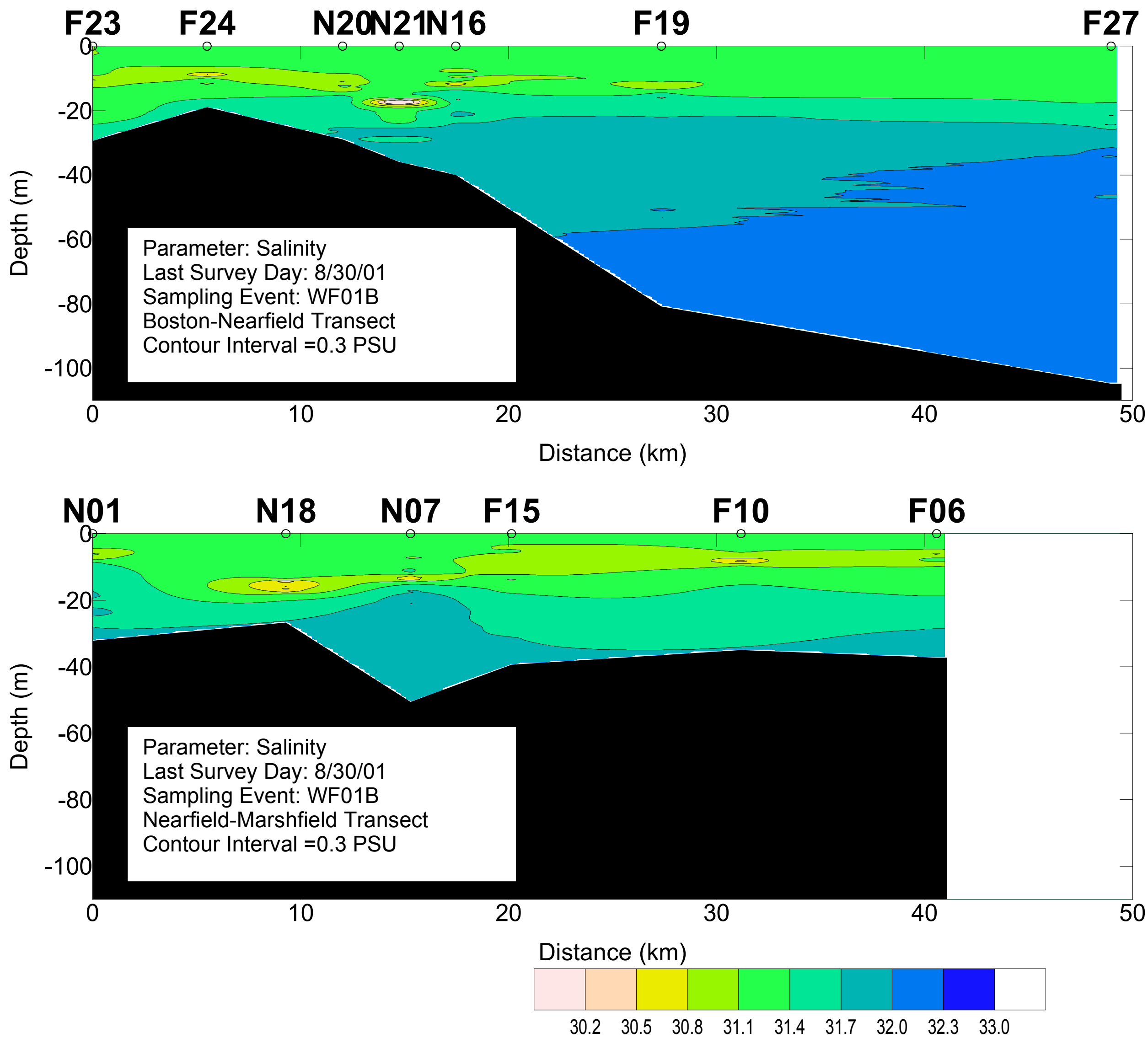



**Figure 4-16. Salinity Vertical (a) Boston-Nearfield and (b) Nearfield-Marshfield Transects for Survey WF01B**

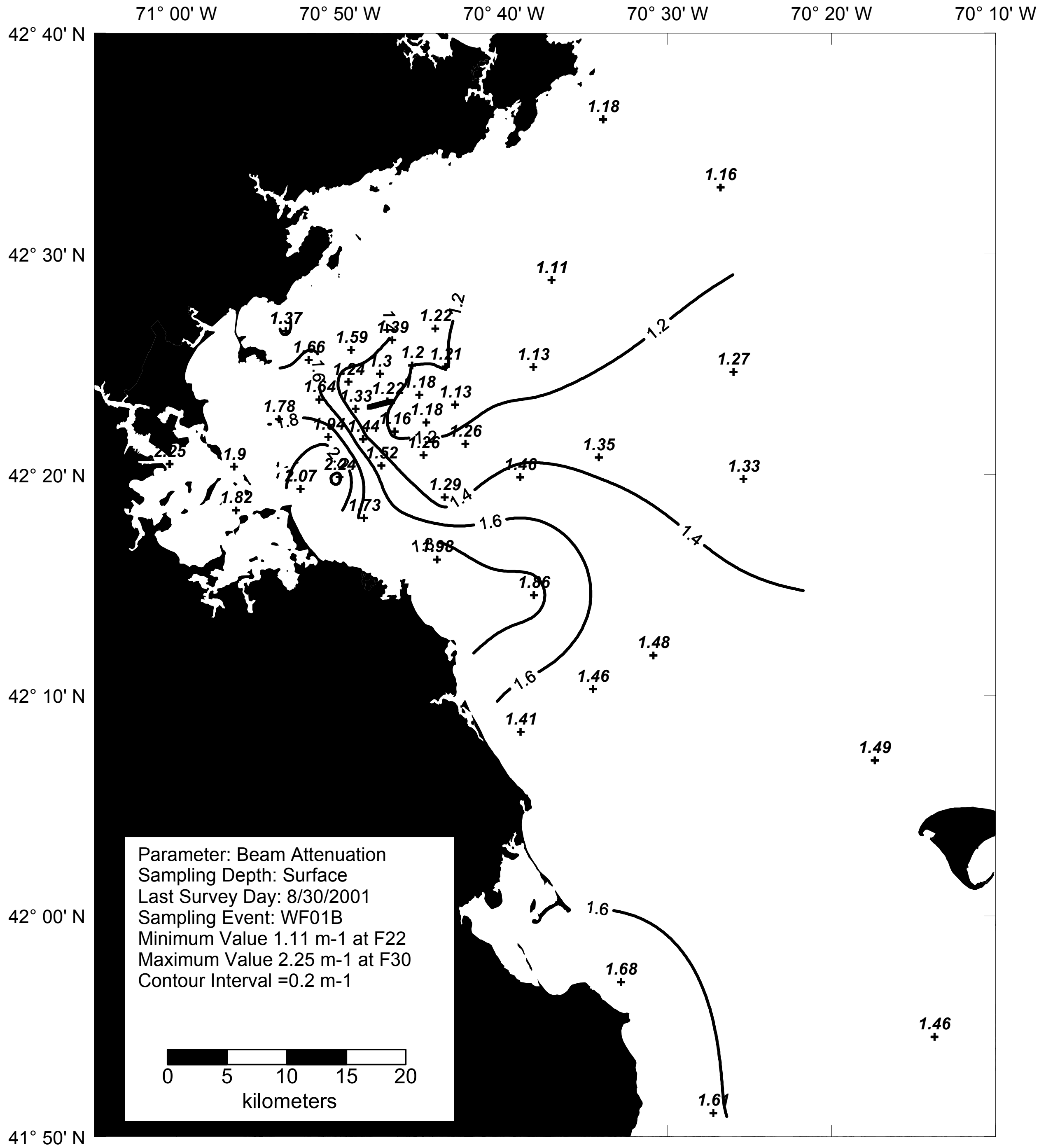



**Figure 4-17. Beam Attenuation Surface Contour Plot for Farfield Survey WF01B (Aug 01)**

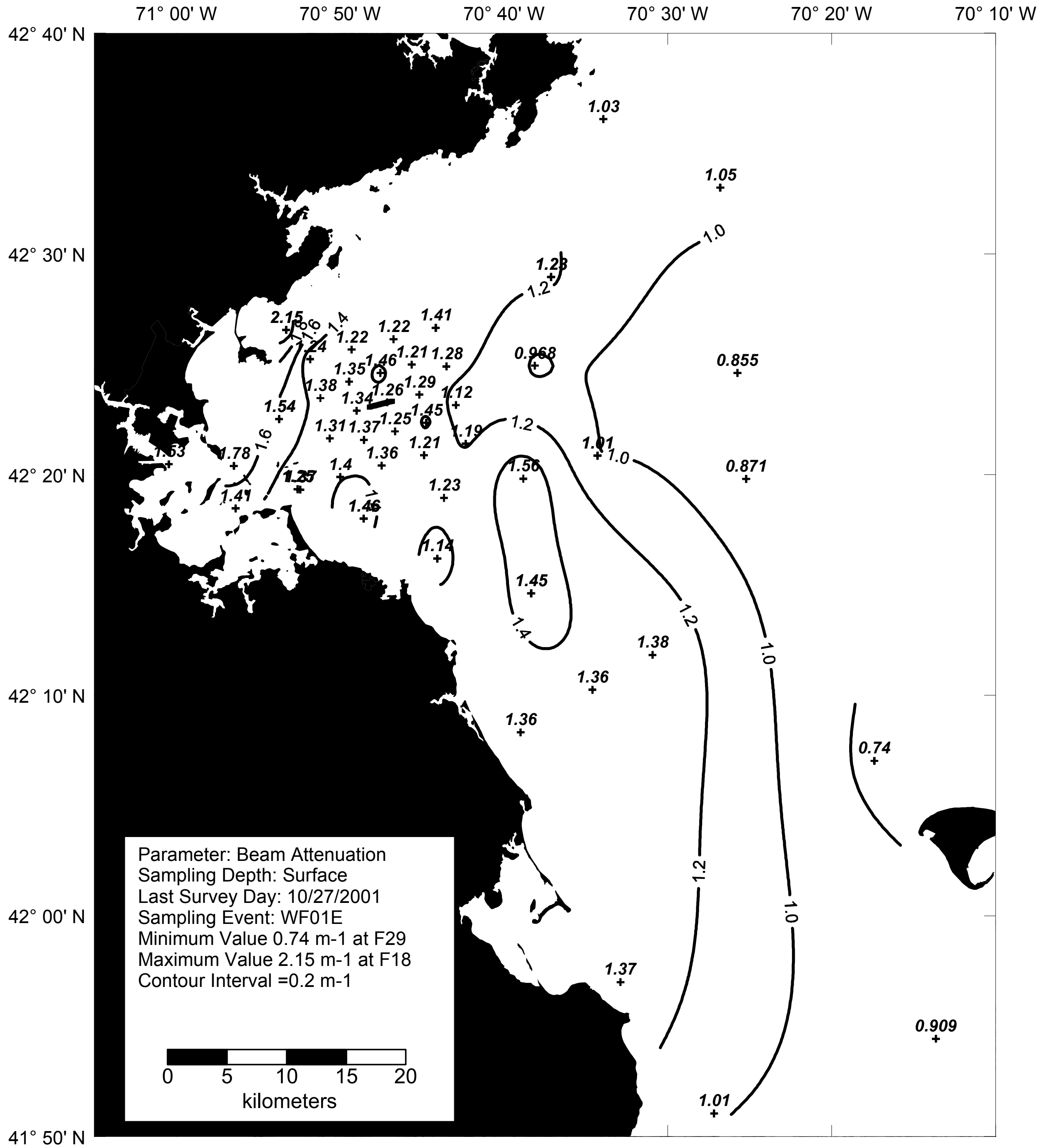



**Figure 4-18. Beam Attenuation Surface Contour Plot for Farfield Survey WF01E (Oct 01)**

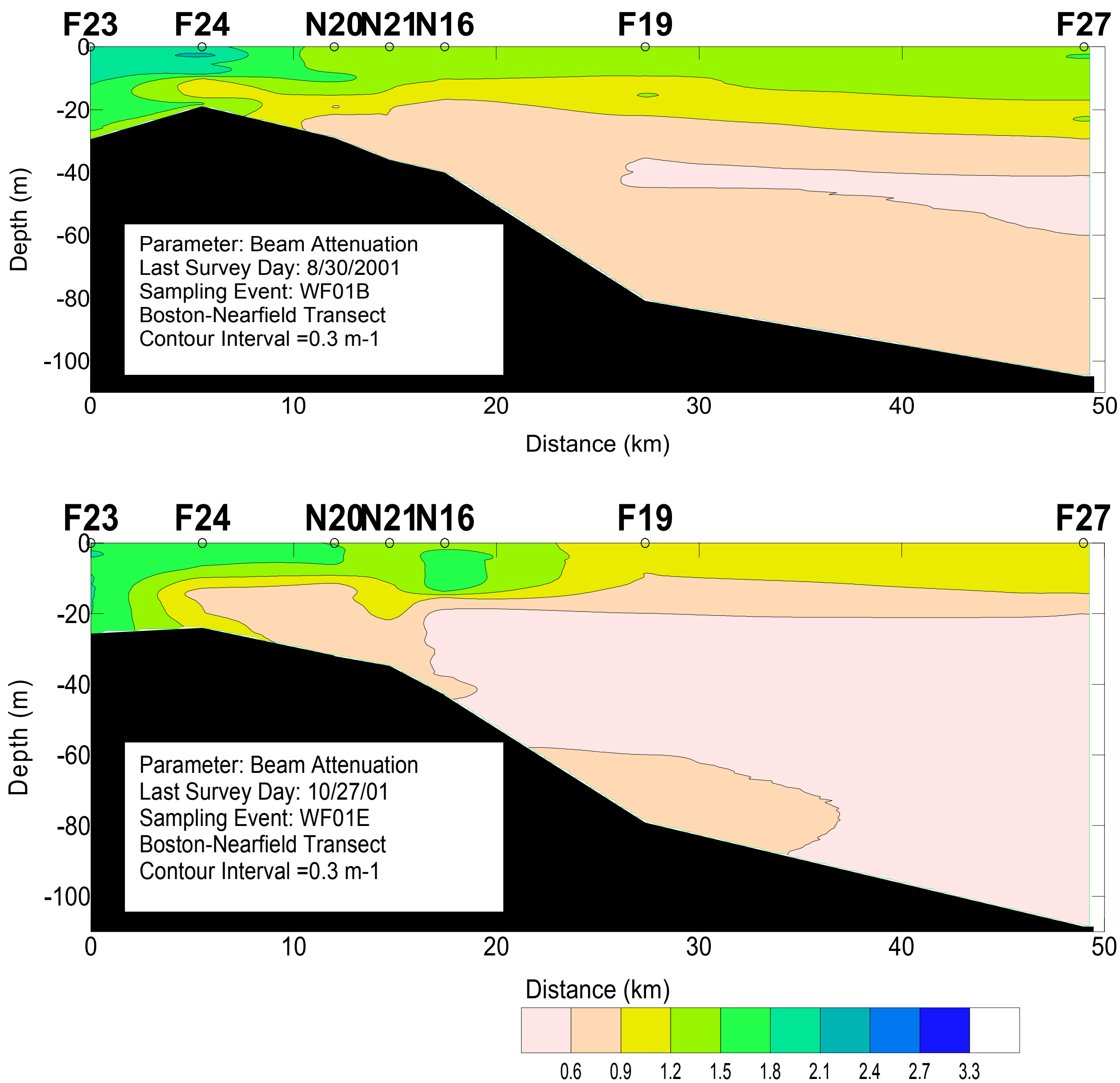



**Figure 4-19. Beam Attenuation Boston-Nearfield Transects for Farfield Surveys WF01B (Aug 01) and WF01E (Oct 01)**

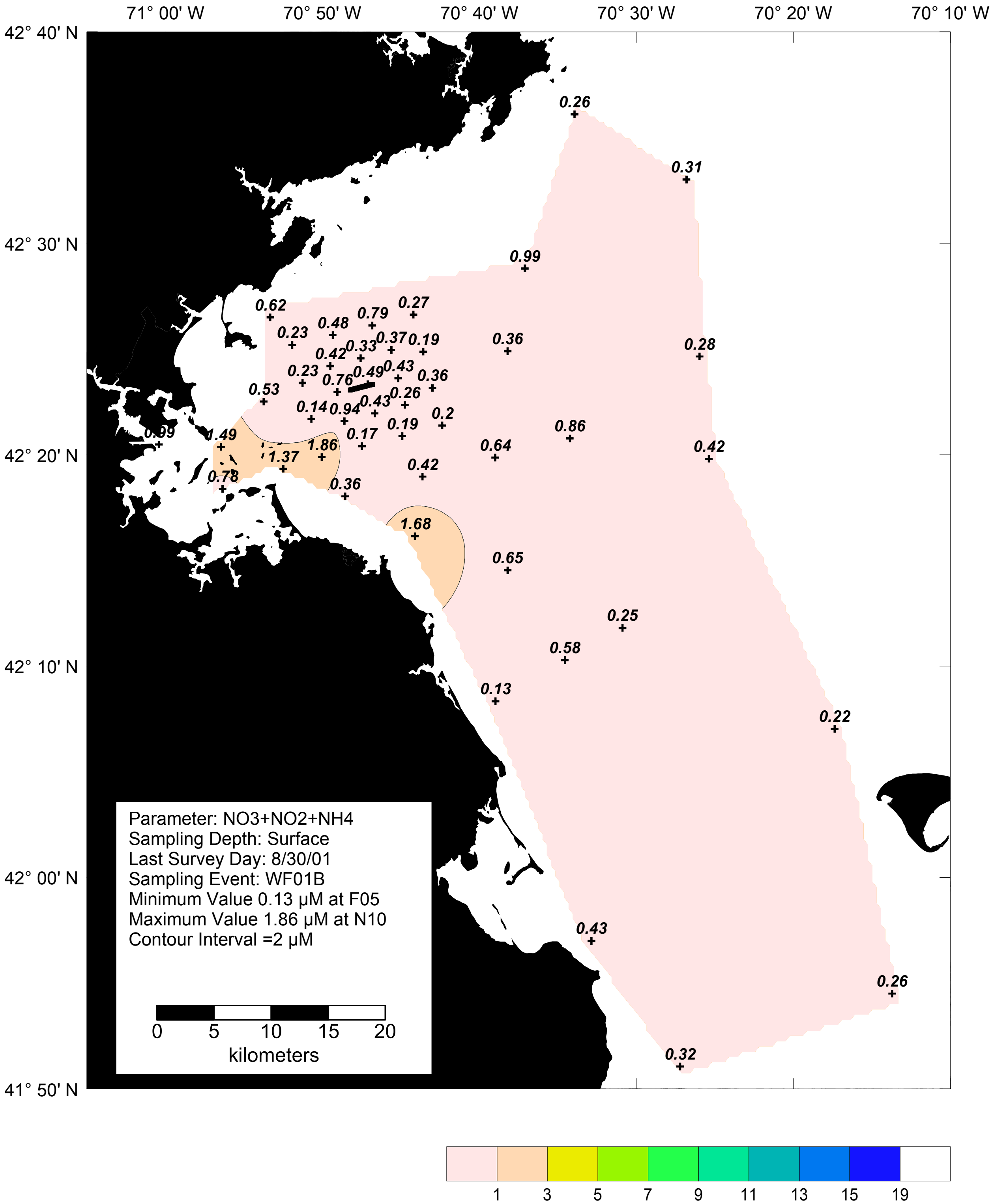



**Figure 4-20. DIN Surface Contour Plot for Farfield Survey WF01B (Aug 01)**

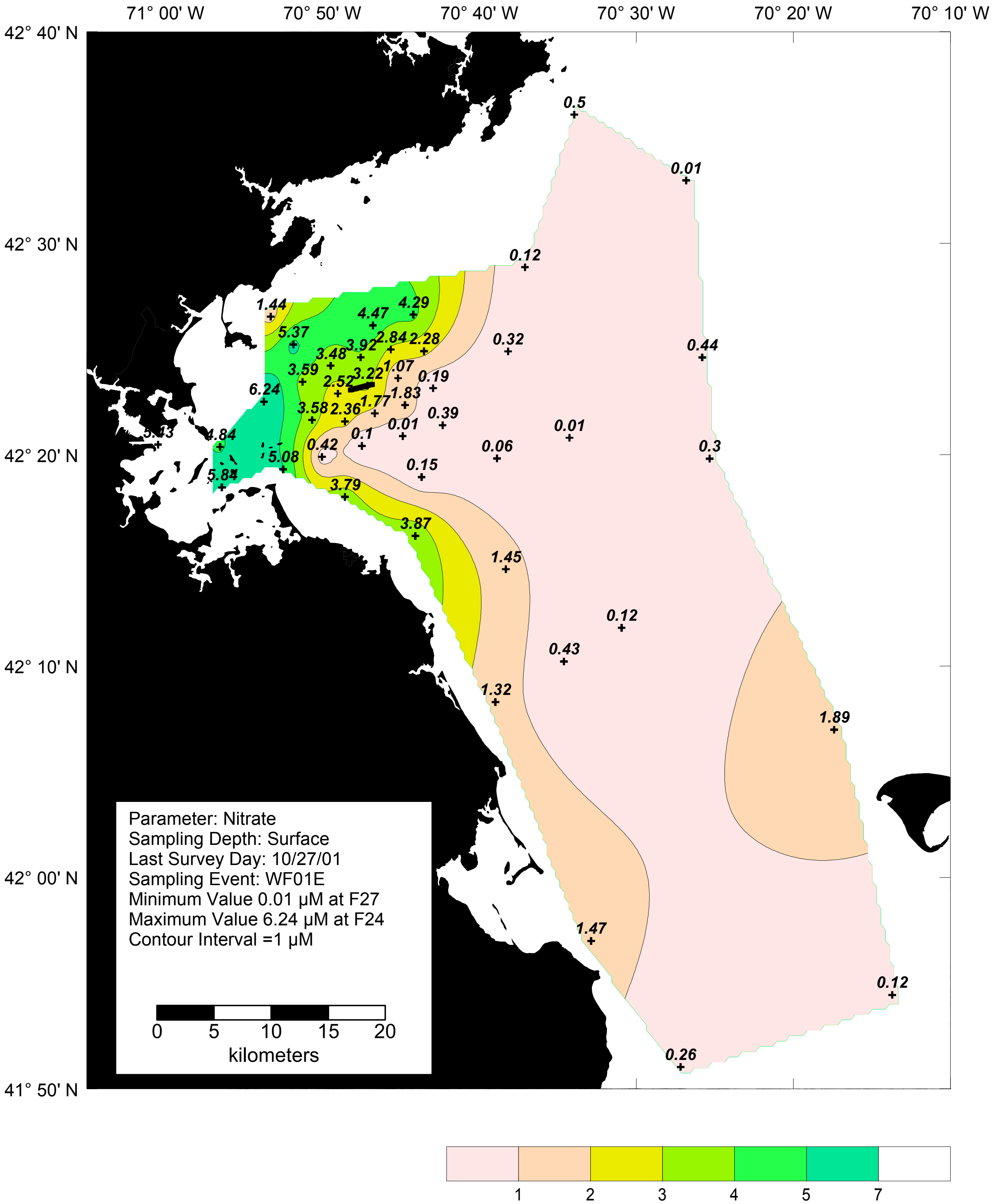



**Figure 4-21. Nitrate Surface Contour Plot for Farfield Survey WF01E (Oct 01)**

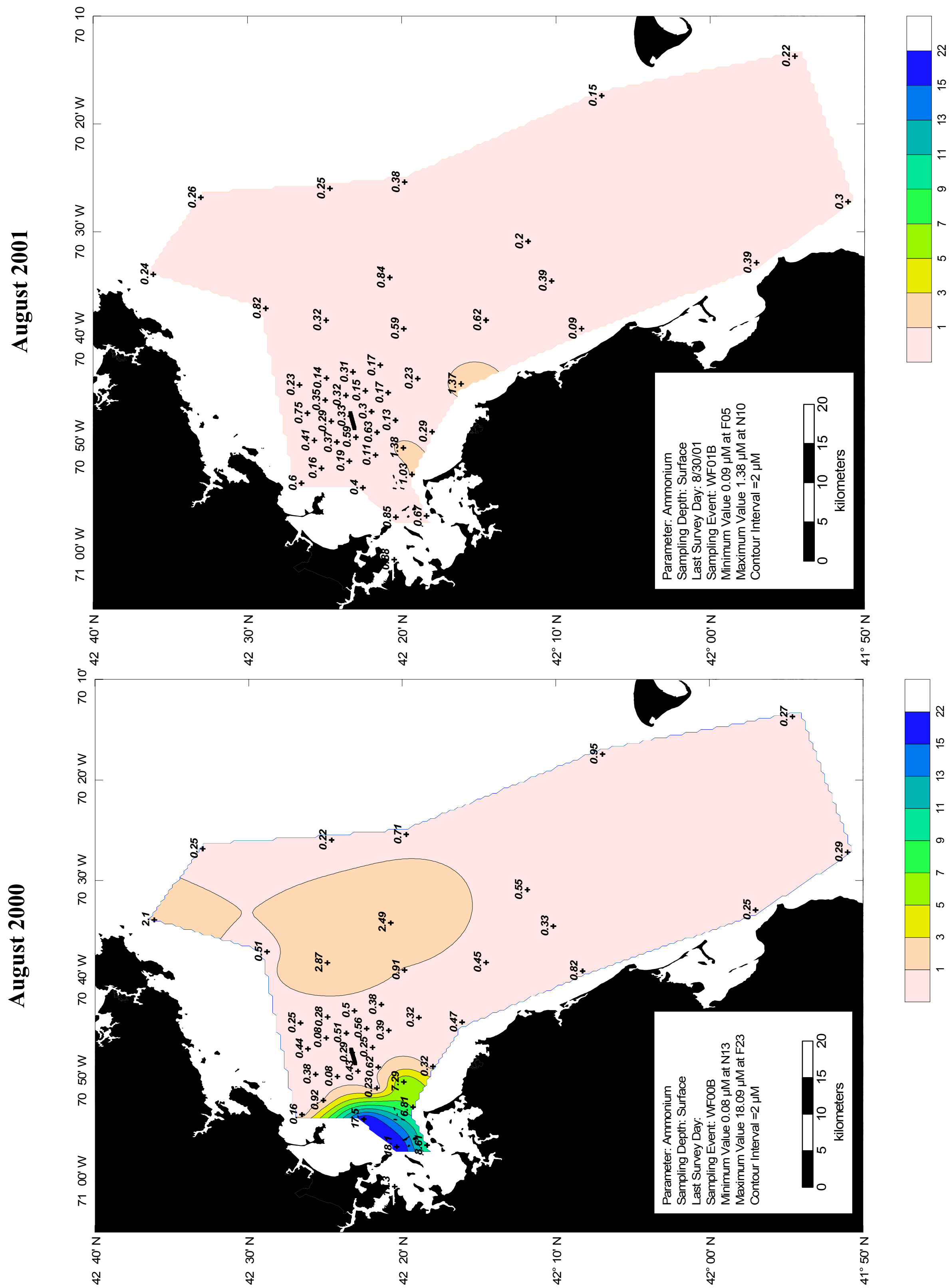



**Figure 4-22. Ammonium Surface Contour Plot for Farfield Surveys WF00B (Aug 00) and WF01B (Aug 01)**

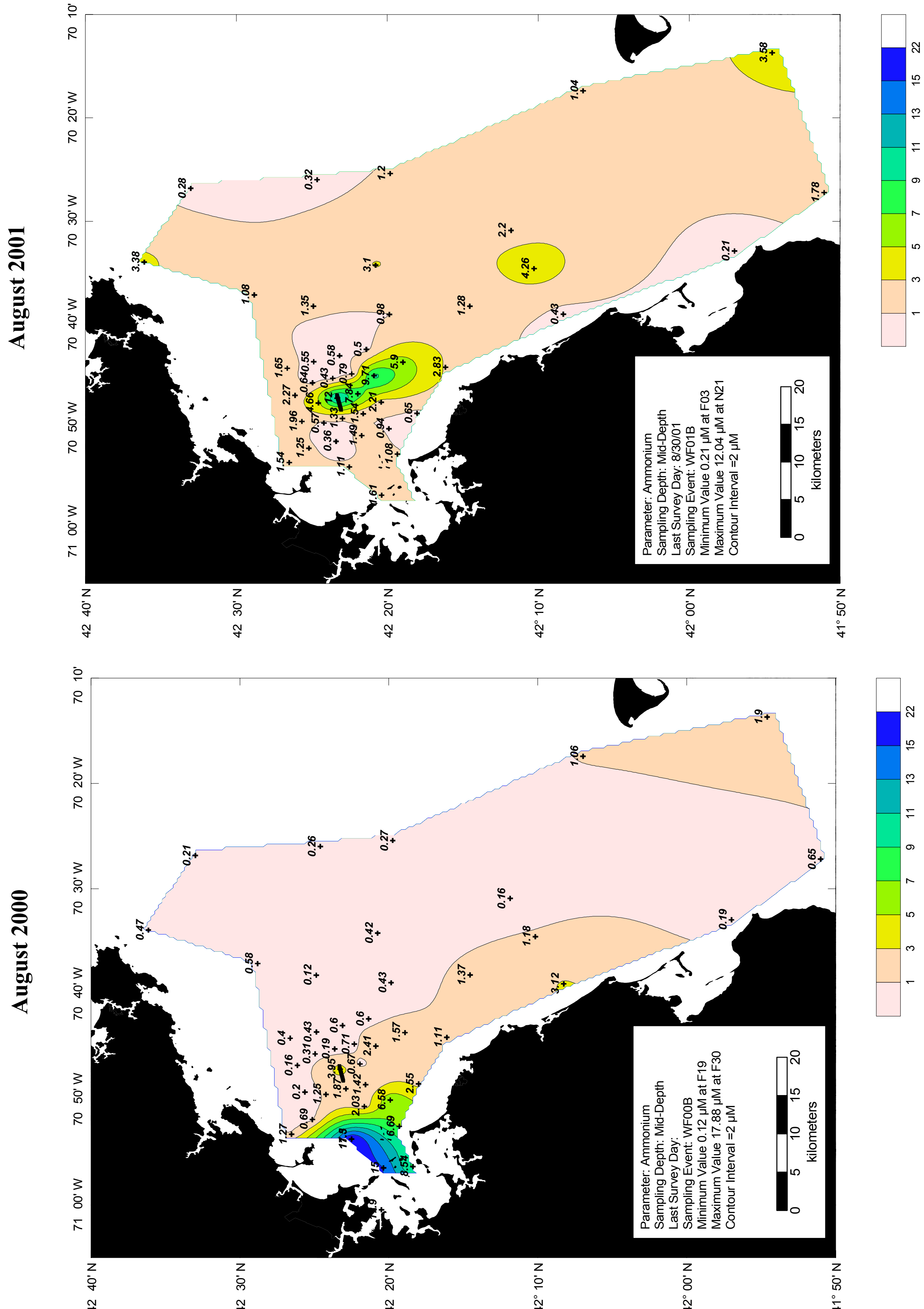



**Figure 4-23. Ammonium Mid-Depth Contour Plot for Farfield Surveys WF00B (Aug 00) and WF01B(Aug 01)**

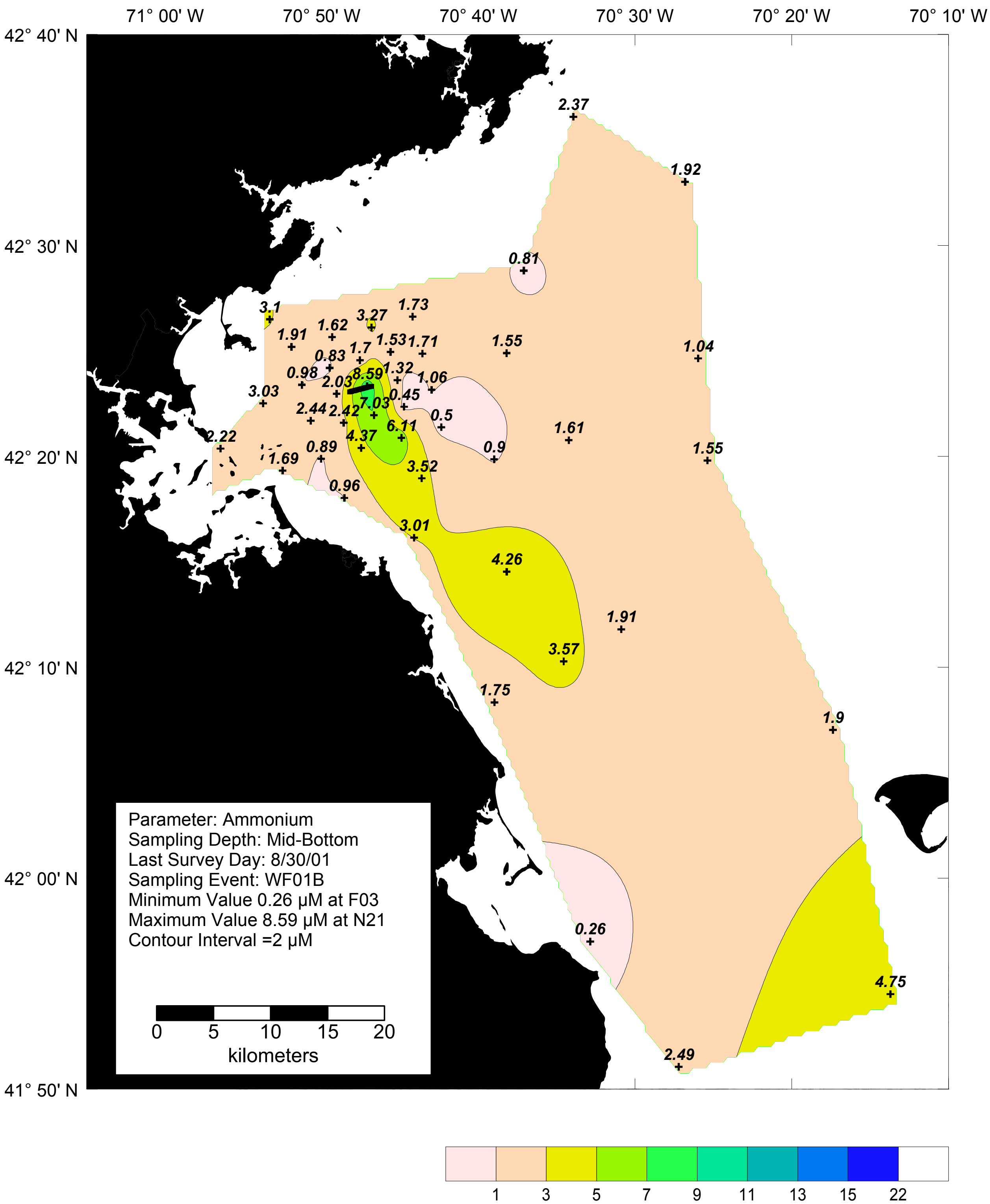



**Figure 4-24. Ammonium Mid-Bottom Contour Plots for Farfield Survey WF01B (Aug 01)**

WN019 WN01G

Surface

Mid-Depth

Bottom

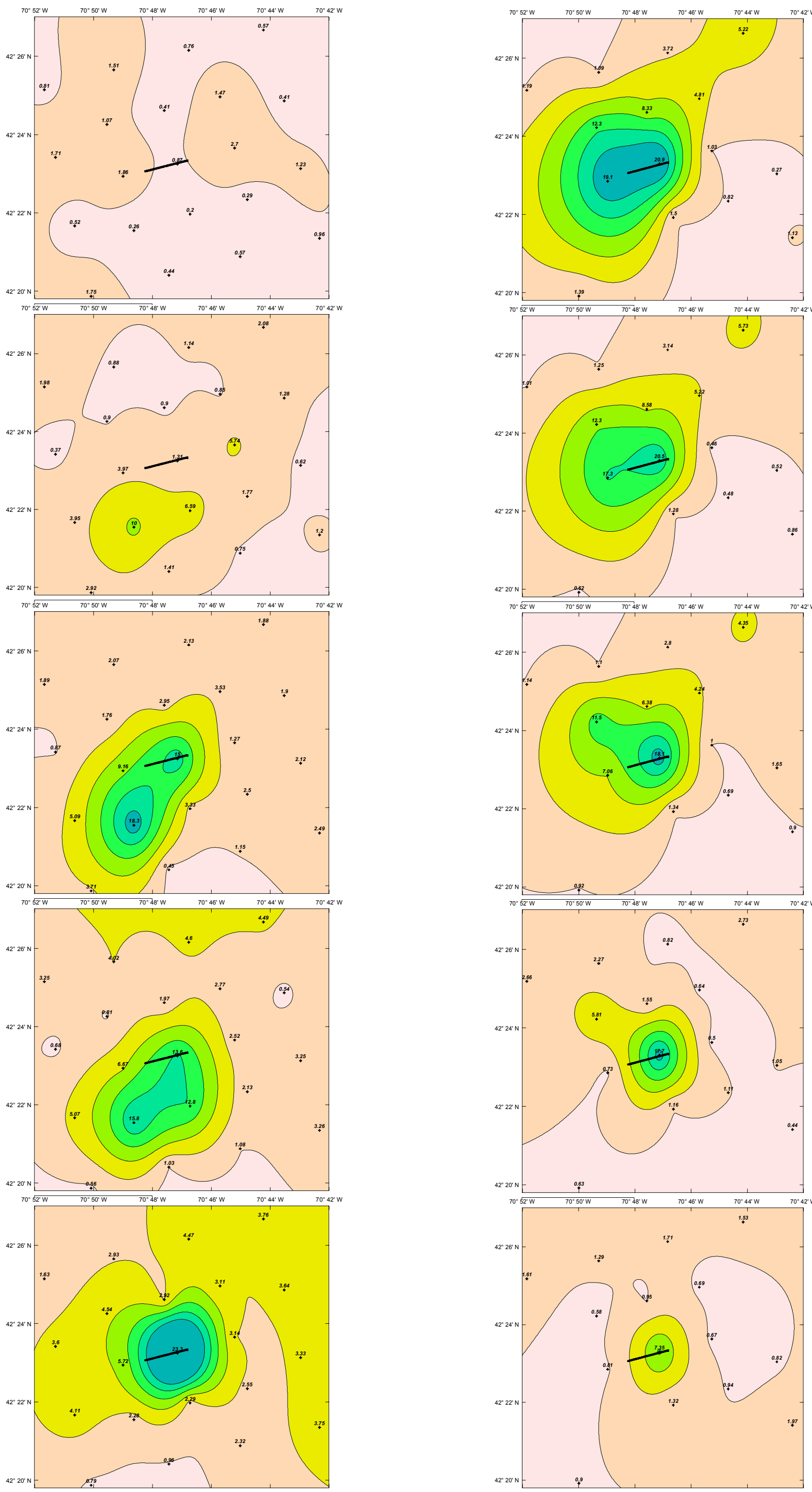


**Figure 4-25. Ammonium Contour Plots at All Depths for Nearfield Surveys WN019 (Jul 01) and WN01G (Dec 01)**

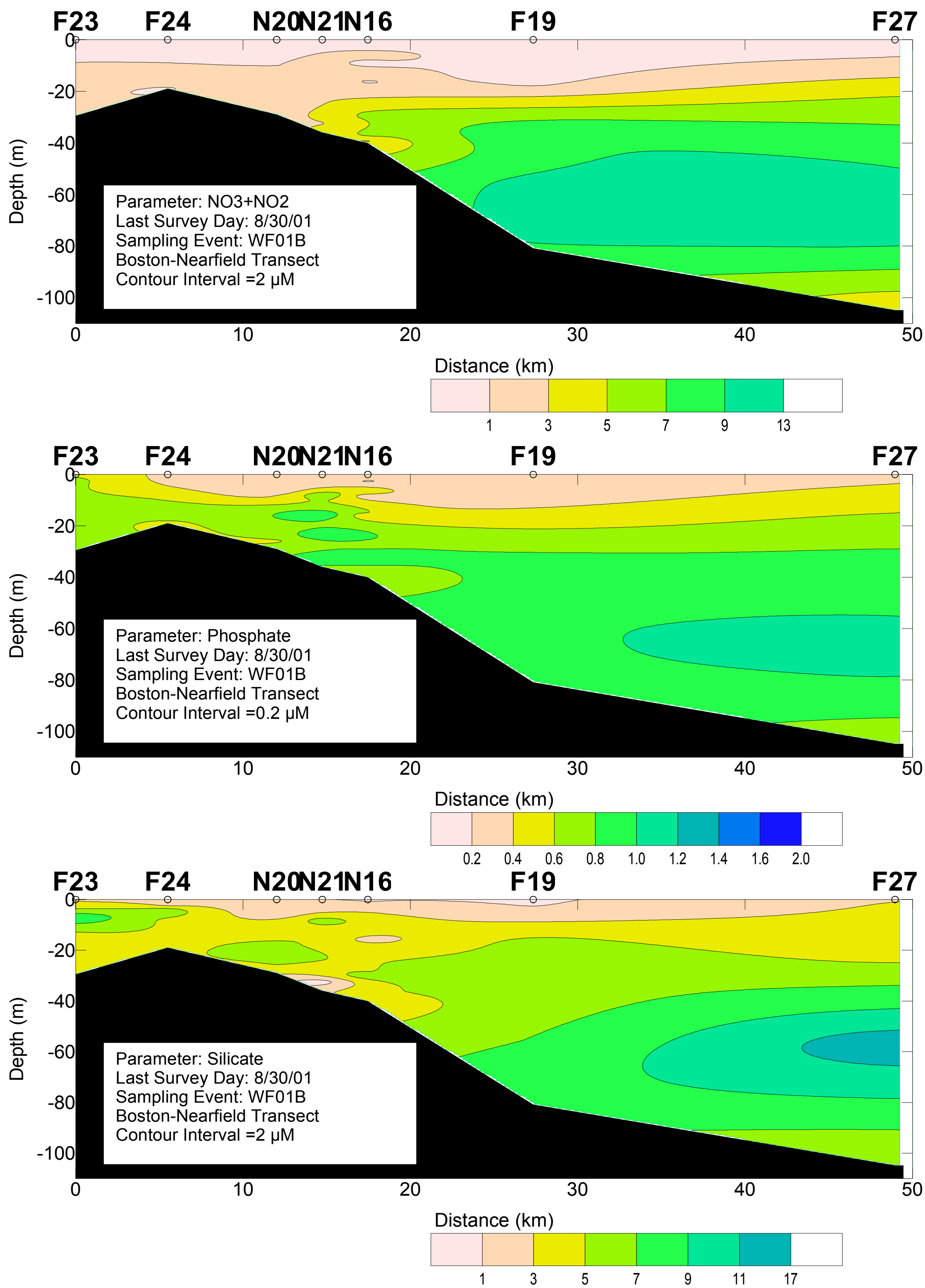



**Figure 4-26. Nitrate, Phosphate, and Silicate Vertical Boston-Nearfield Transect Plots for Farfield Survey WF01B (Aug 01)**

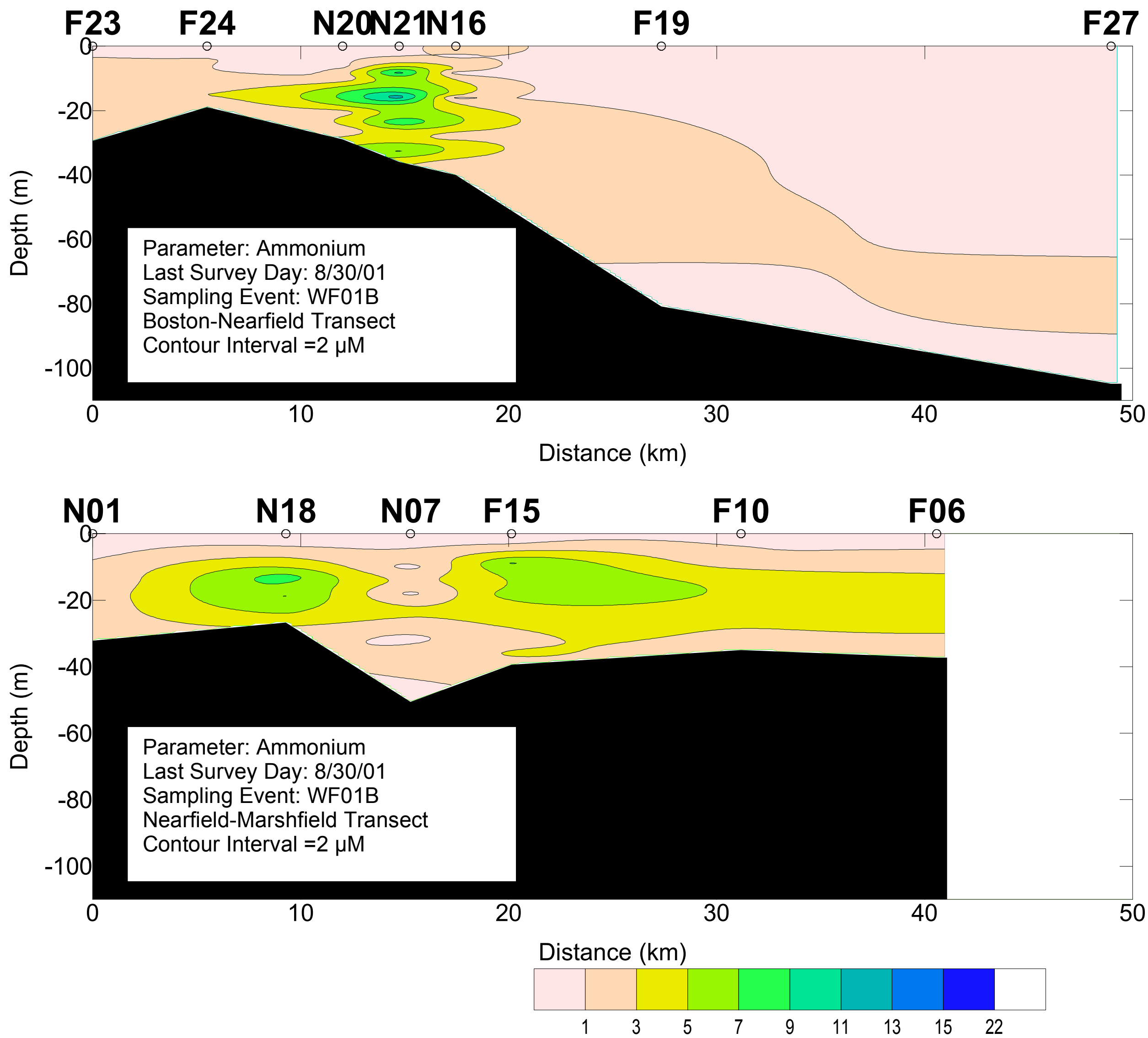



**Figure 4-27. Ammonium Vertical Boston-Nearfield and Nearfield-Marshfield Transect Plots for Farfield Survey WF01B (Aug 01)**

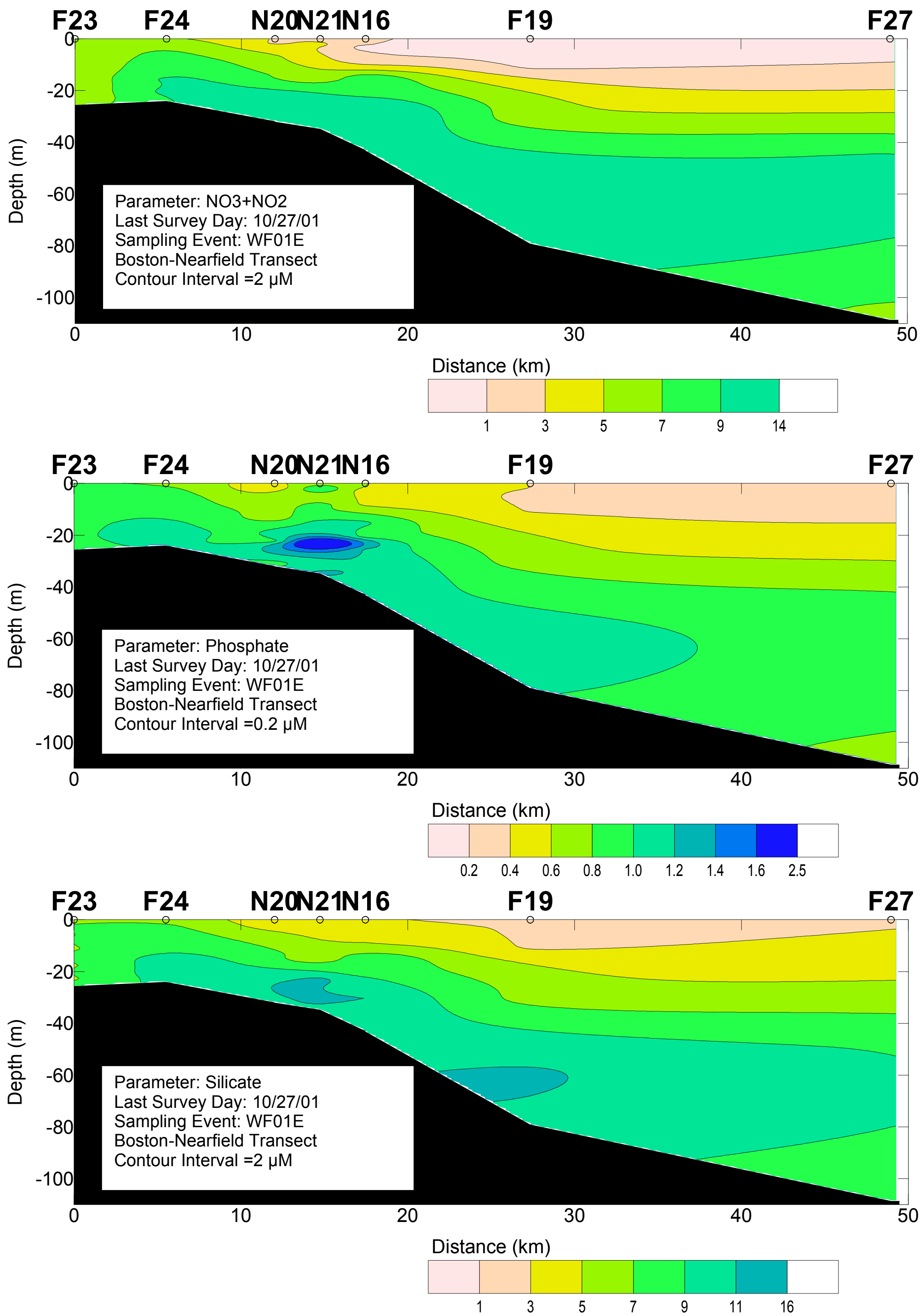



**Figure 4-28. Nitrate, Phosphate, and Silicate Vertical Boston-Nearfield Transect Plots for Farfield Survey WF01E (Oct 01)**

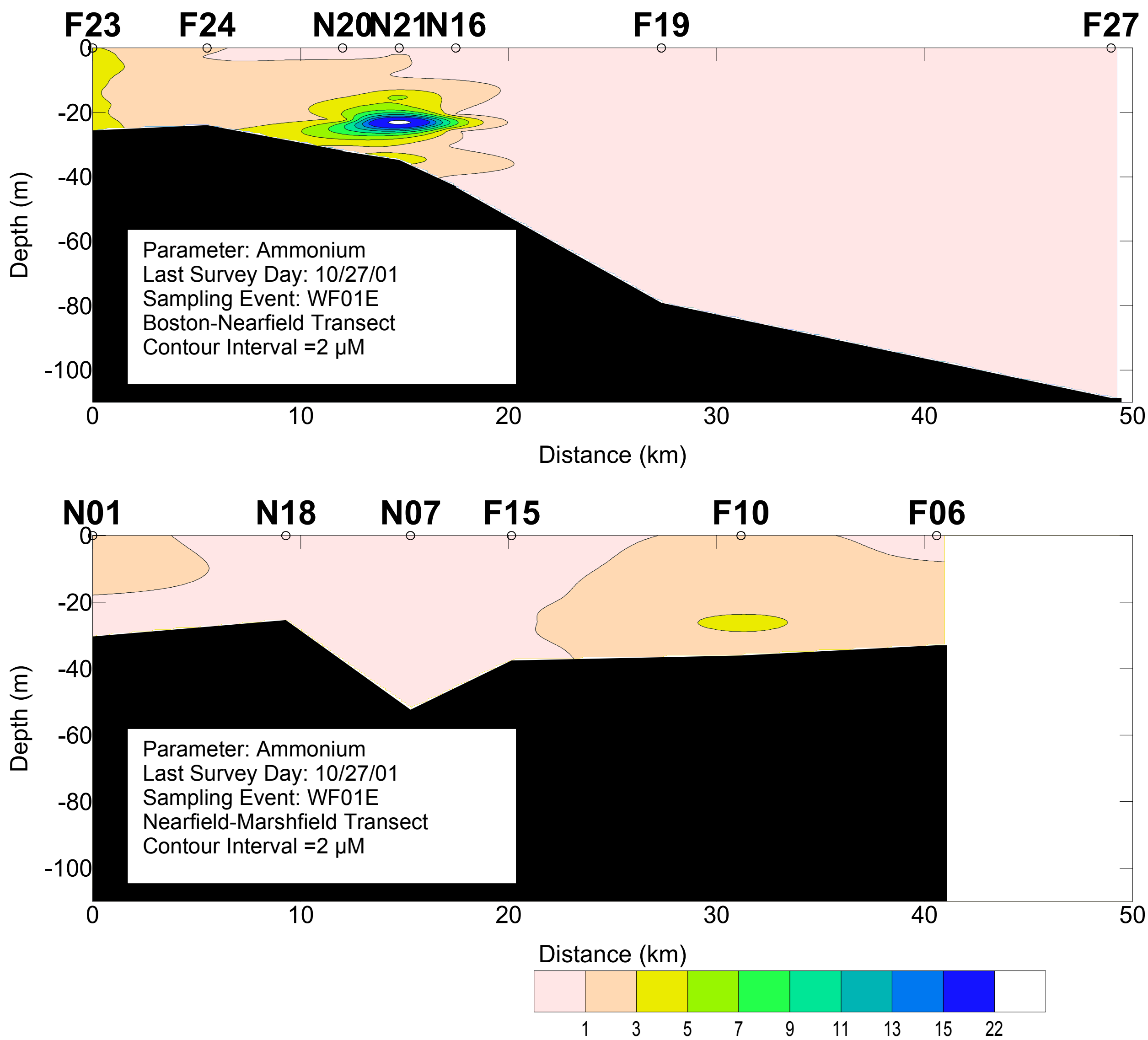



**Figure 4-29. Ammonium Vertical Boston-Nearfield and Nearfield-Marshfield Transect Plots for Farfield Survey WF01E (Oct 01)**

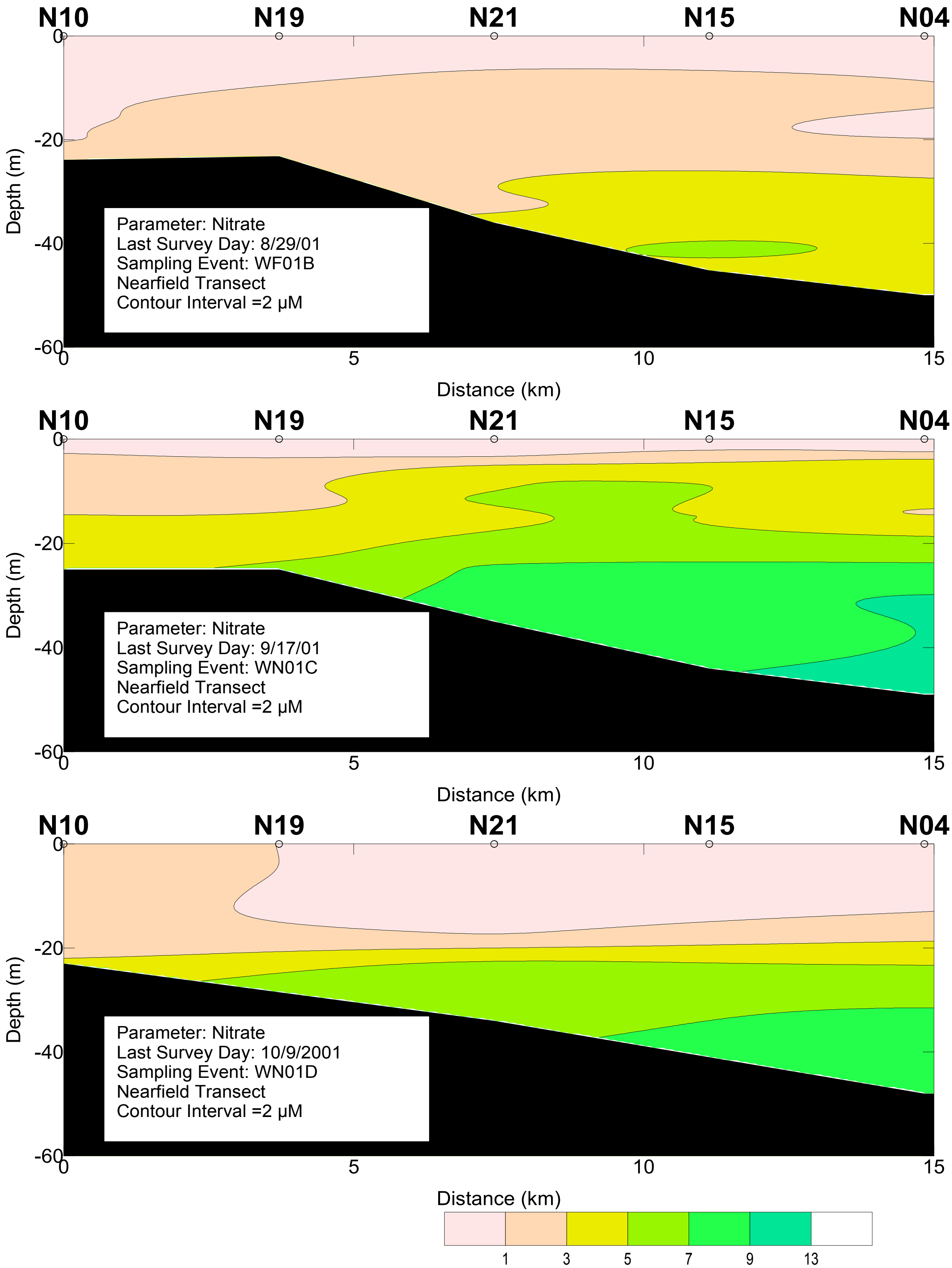



**Figure 4-30. Nitrate Vertical Nearfield Transects for Surveys WF01B, WN01C, and WN01D**

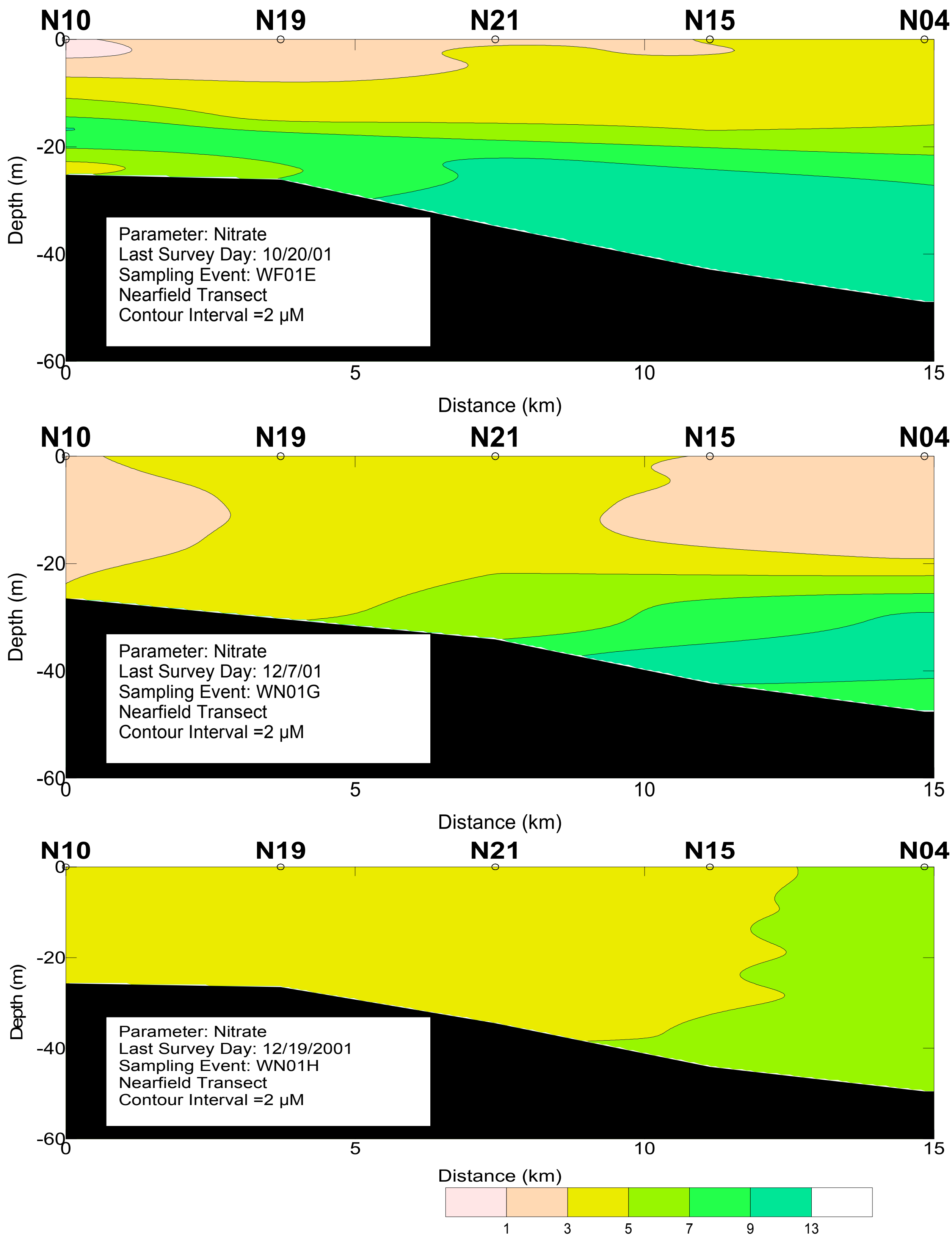



**Figure 4-31. Nitrate Vertical Nearfield Transects for Surveys WF01E, WN01G, and WN01H**

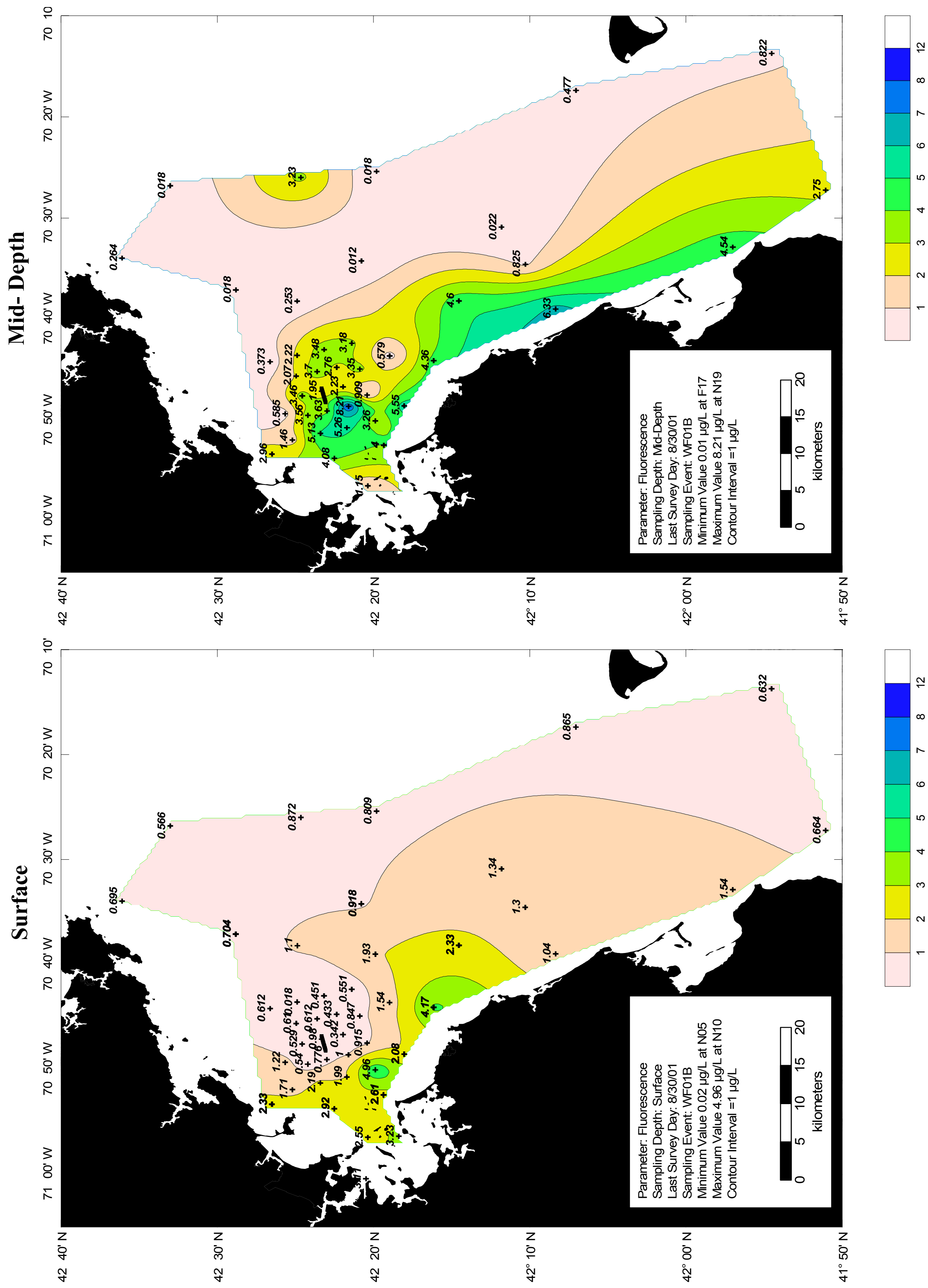



**Figure 4-32. Fluorescence Surface and Mid-Depth Contour Plots for Farfield Survey WF01B (Aug 01)**

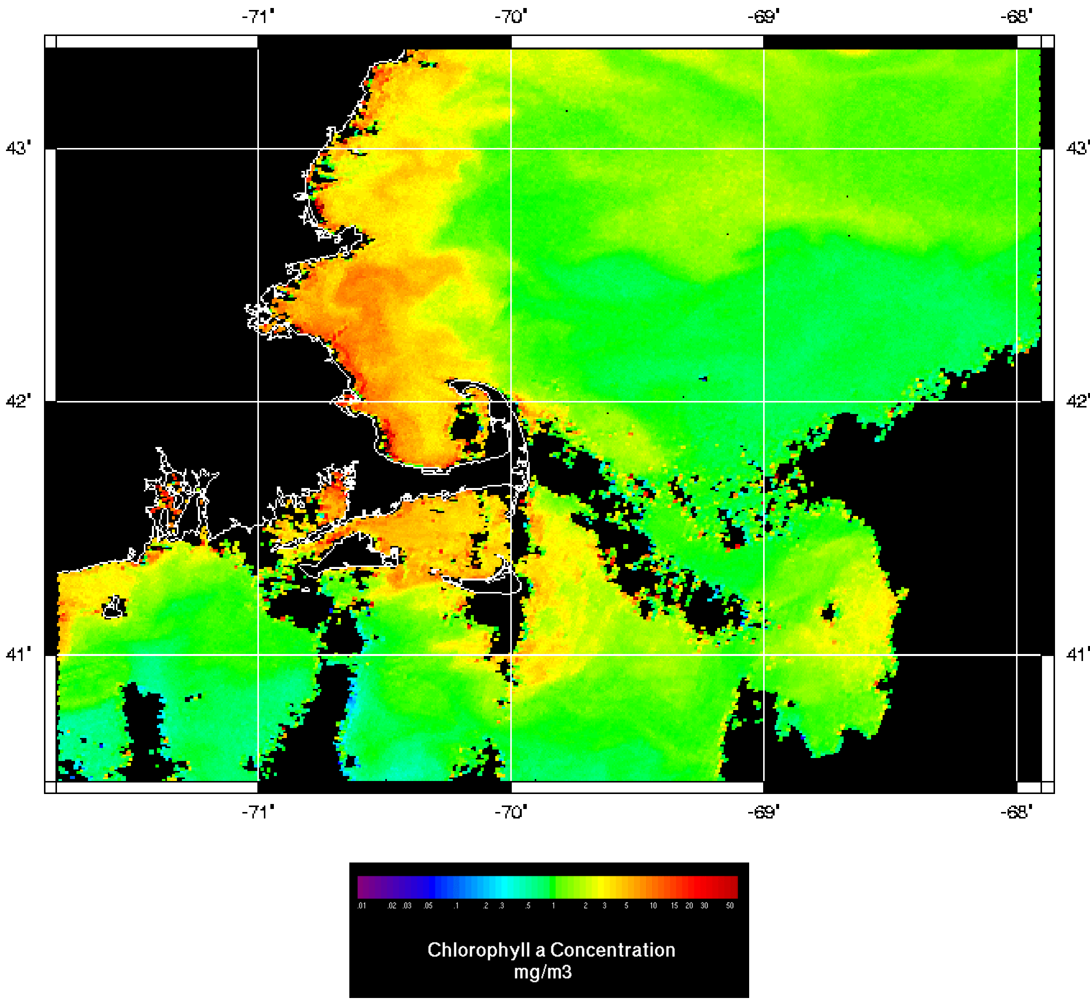
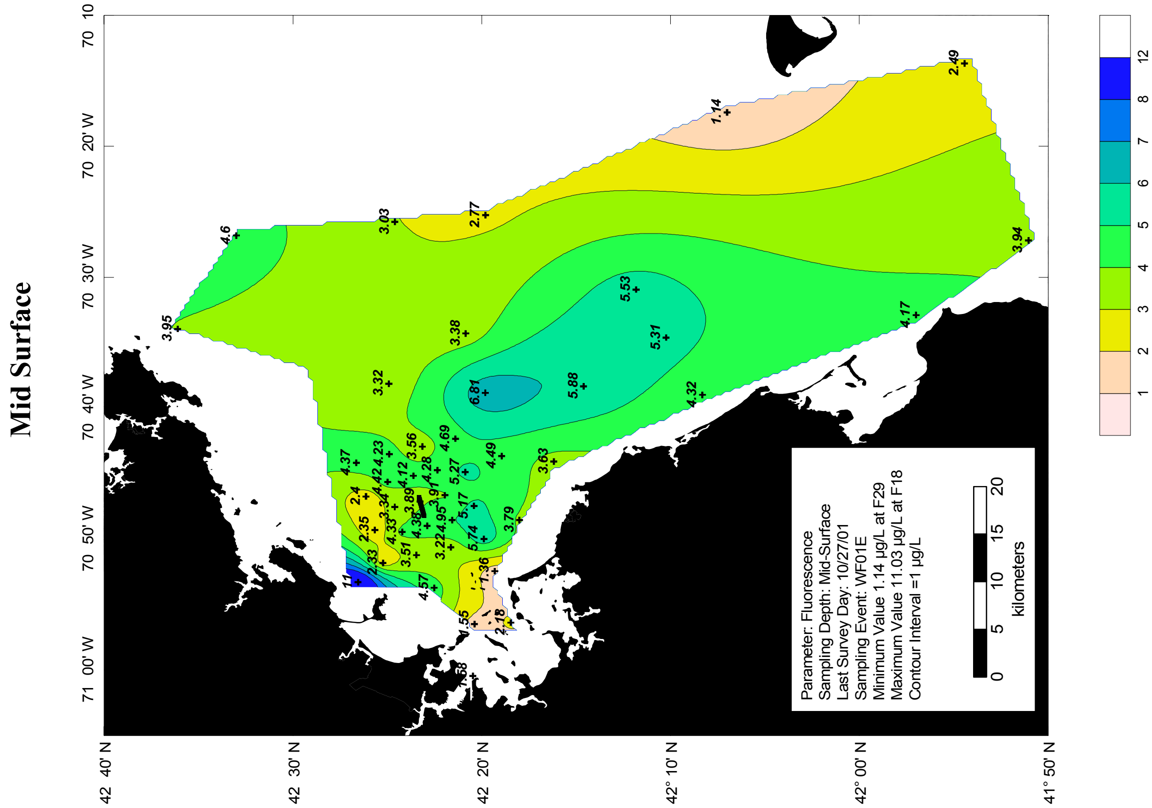



**Figure 4-33. SeaWiFS Chlorophyll Image for September 5, 2001**



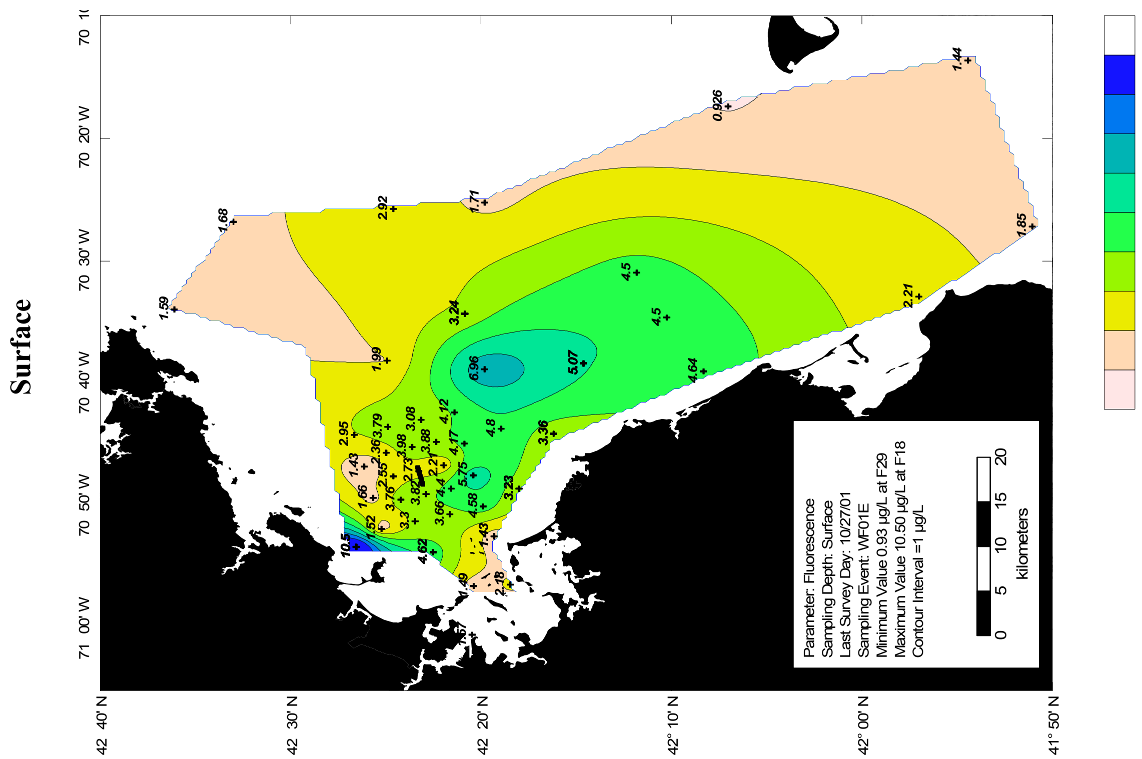




**Figure 4-34. Fluorescence Surface and Mid-Surface Contour Plots for Farfield Survey WF01E (Oct 01)**

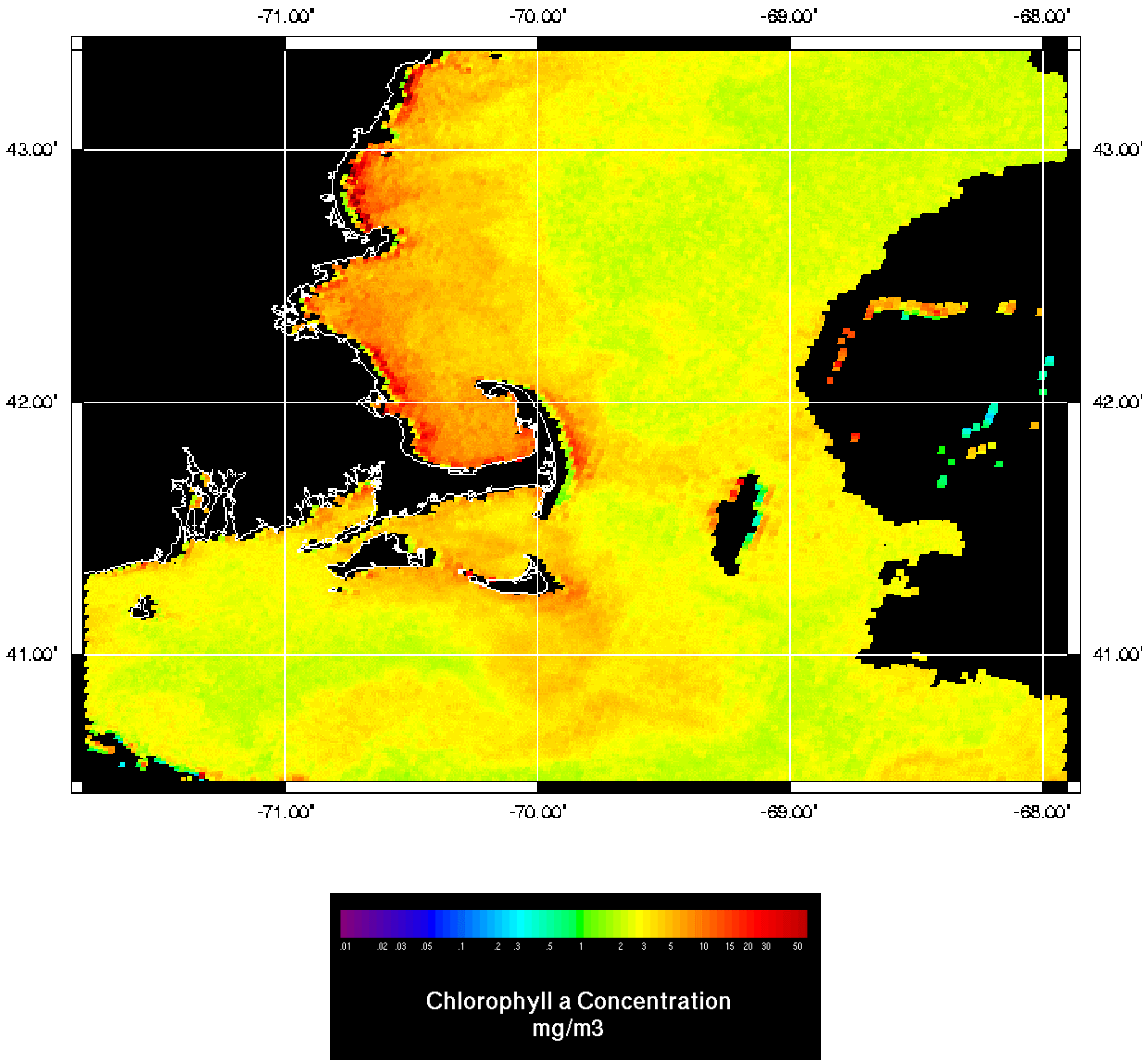



**Figure 4-35. SeaWiFS Chlorophyll Image for December 5, 2001**

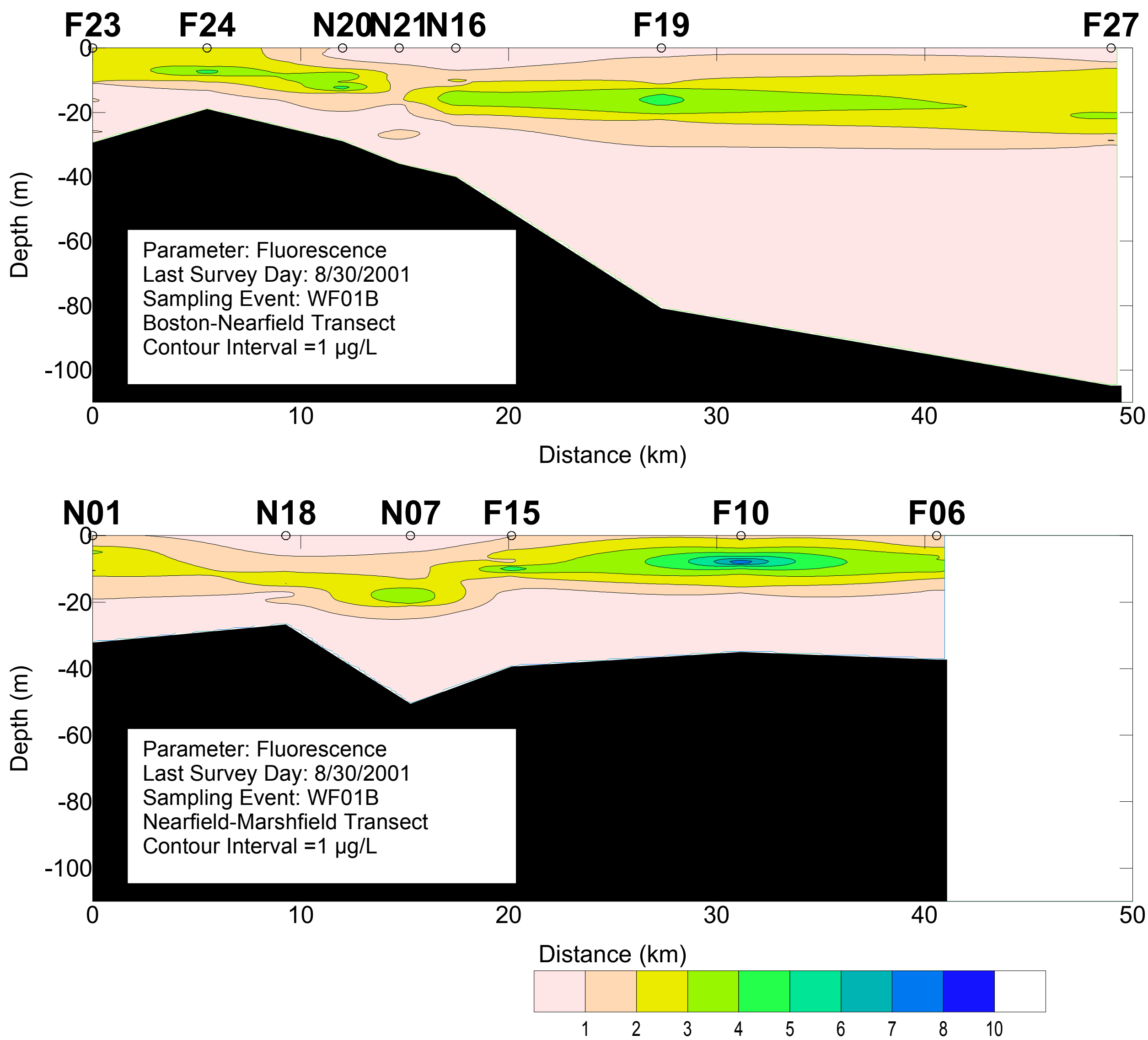



**Figure 4-36. Fluorescence Vertical Boston-Nearfield and Nearfield-Marshfield Transect Plots for Farfield Survey WF01B (Aug 01)**

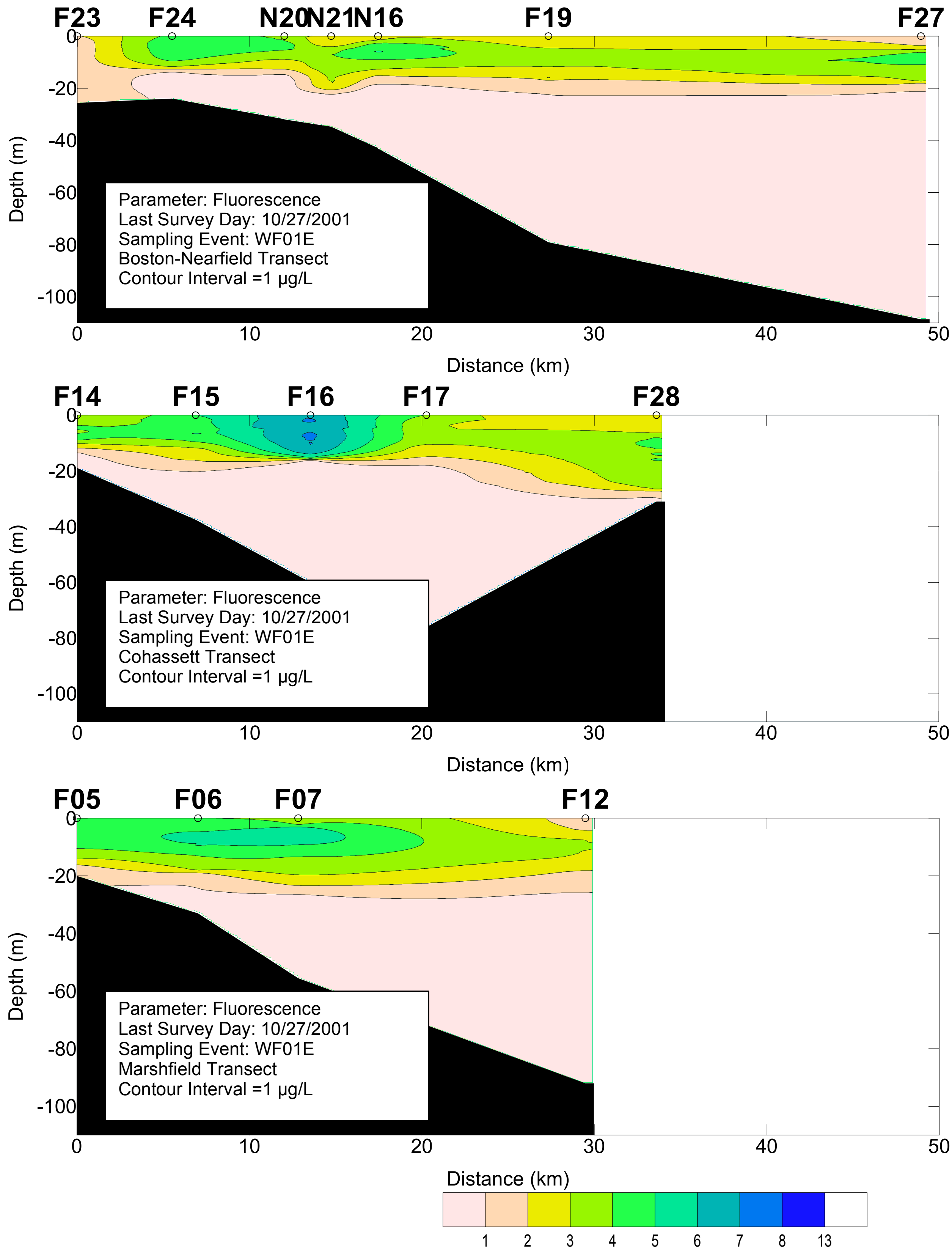



**Figure 4-37. Fluorescence Vertical Transect Plots for Farfield Survey WF01E (Oct 01)**

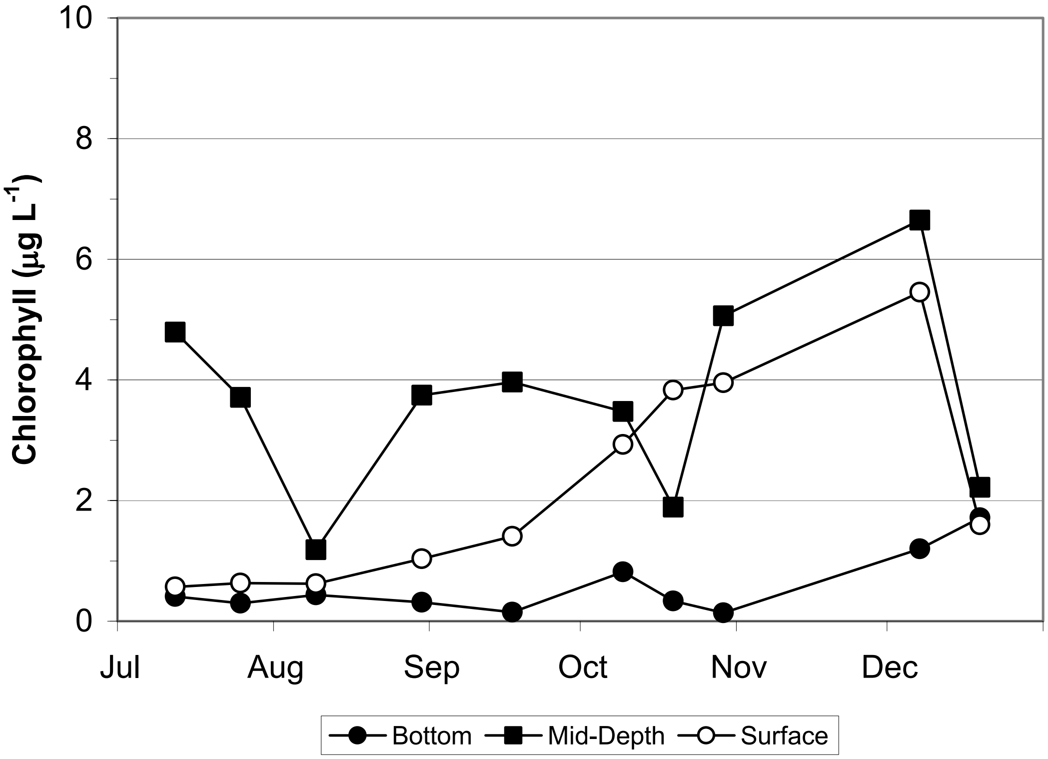



**Figure 4-38. Time Series of Average Fluorescence in the Nearfield – Surface, Mid-Depth, and Bottom Depth**

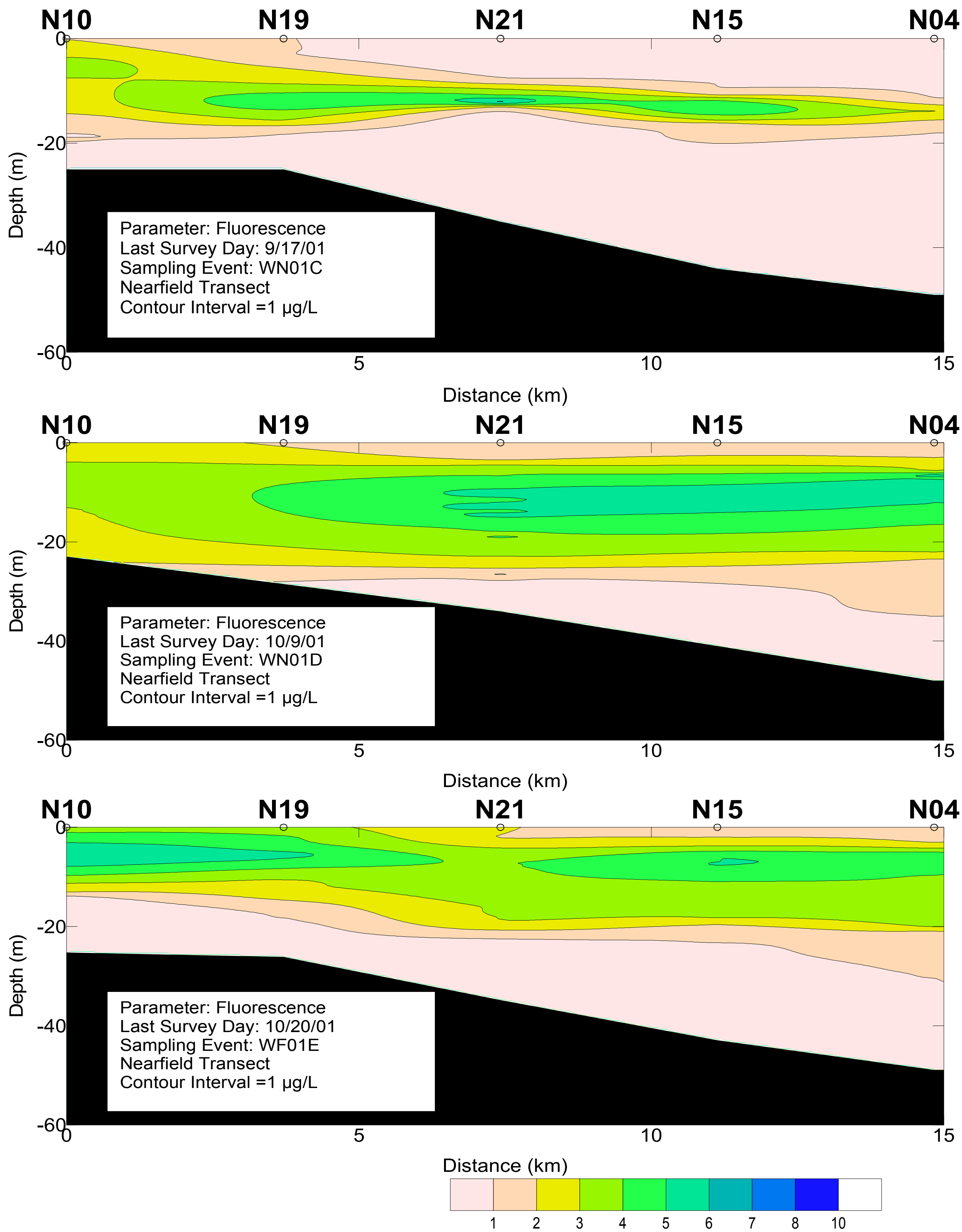



**Figure 4-39. Fluorescence Vertical Nearfield Transect Plots for Surveys (a) WN01C, (b) WN01D, and (c) WF01E**

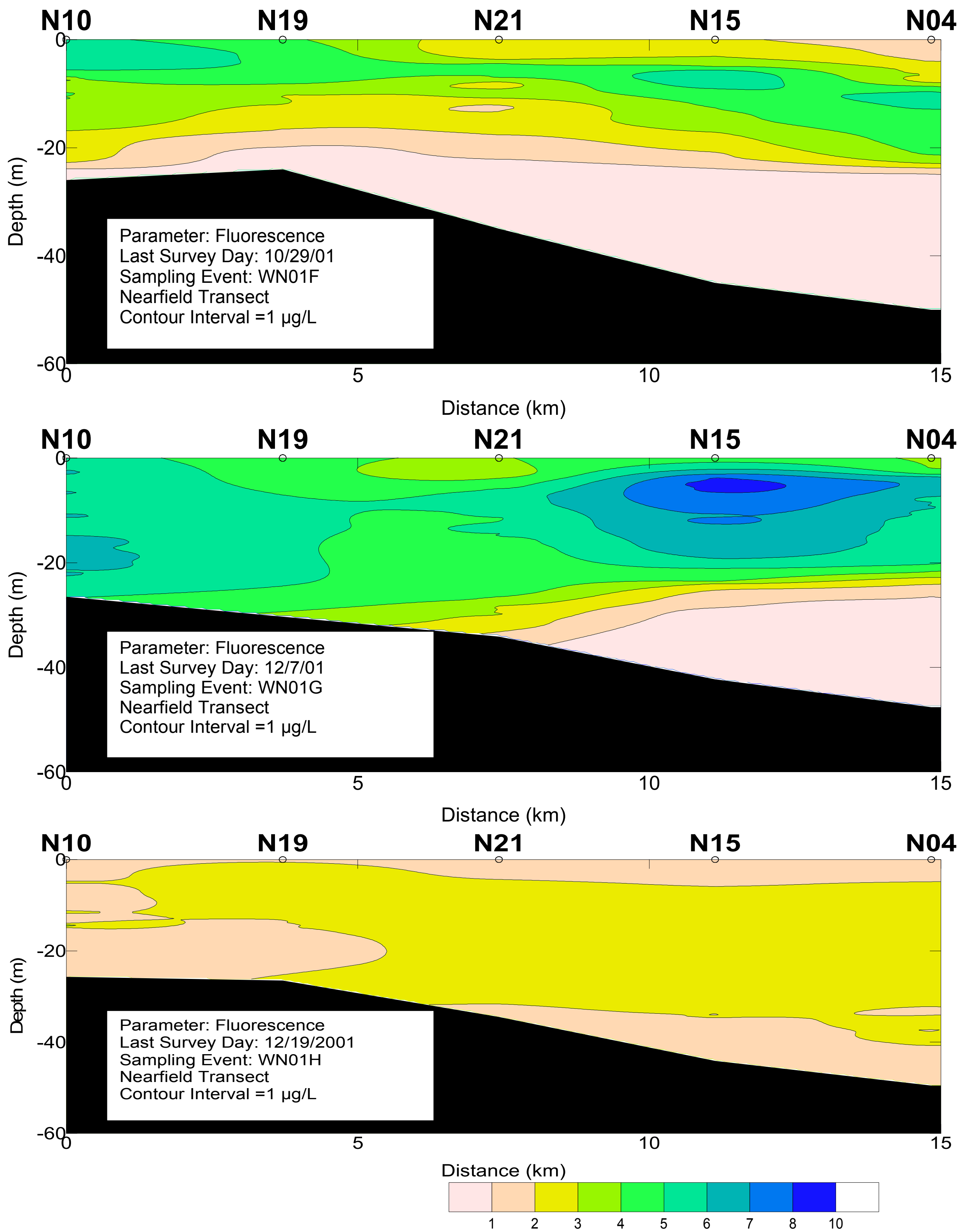



**Figure 4-40. Fluorescence Vertical Nearfield Transect Plots for Surveys (a) WN01F, (b) WN01G, and (c) WN01H**

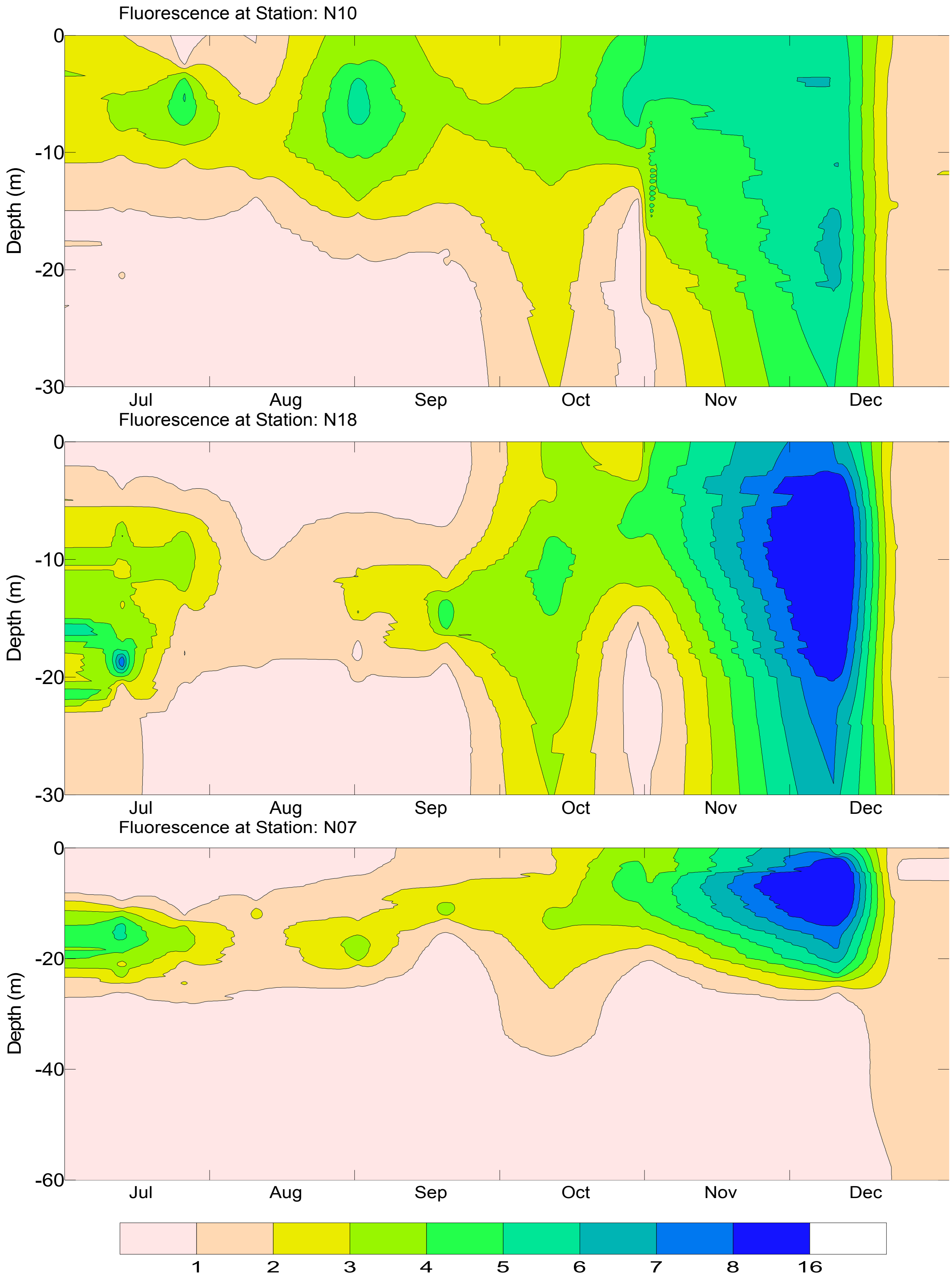



**Figure 4-41. Fluorescence Depth vs. Time Contour Plots for Stations N10, N18, and N07**

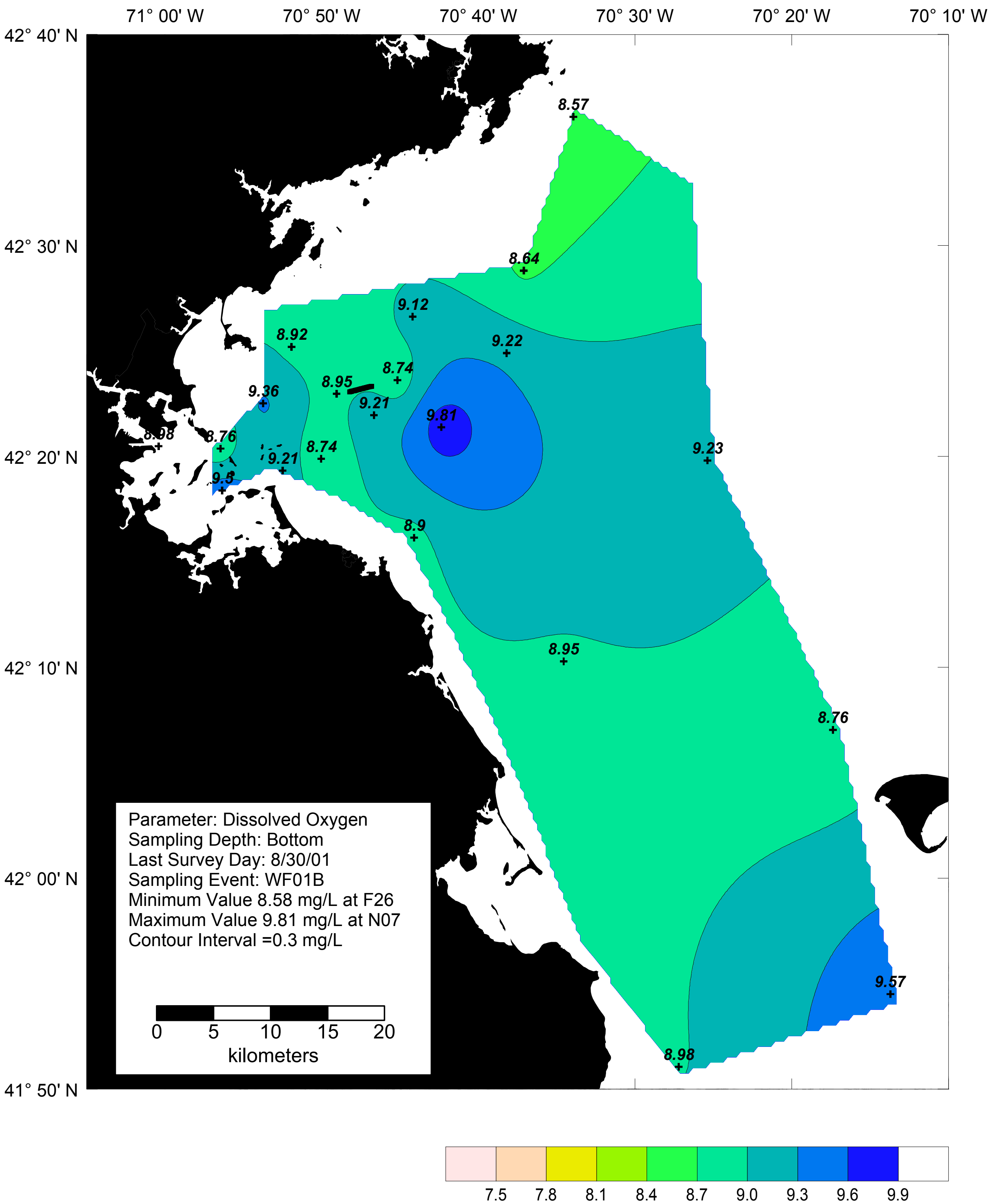



**Figure 4-42. Dissolved Oxygen Bottom Contour (Bottle Data) in the Farfield Survey WF01B (Aug 01)**

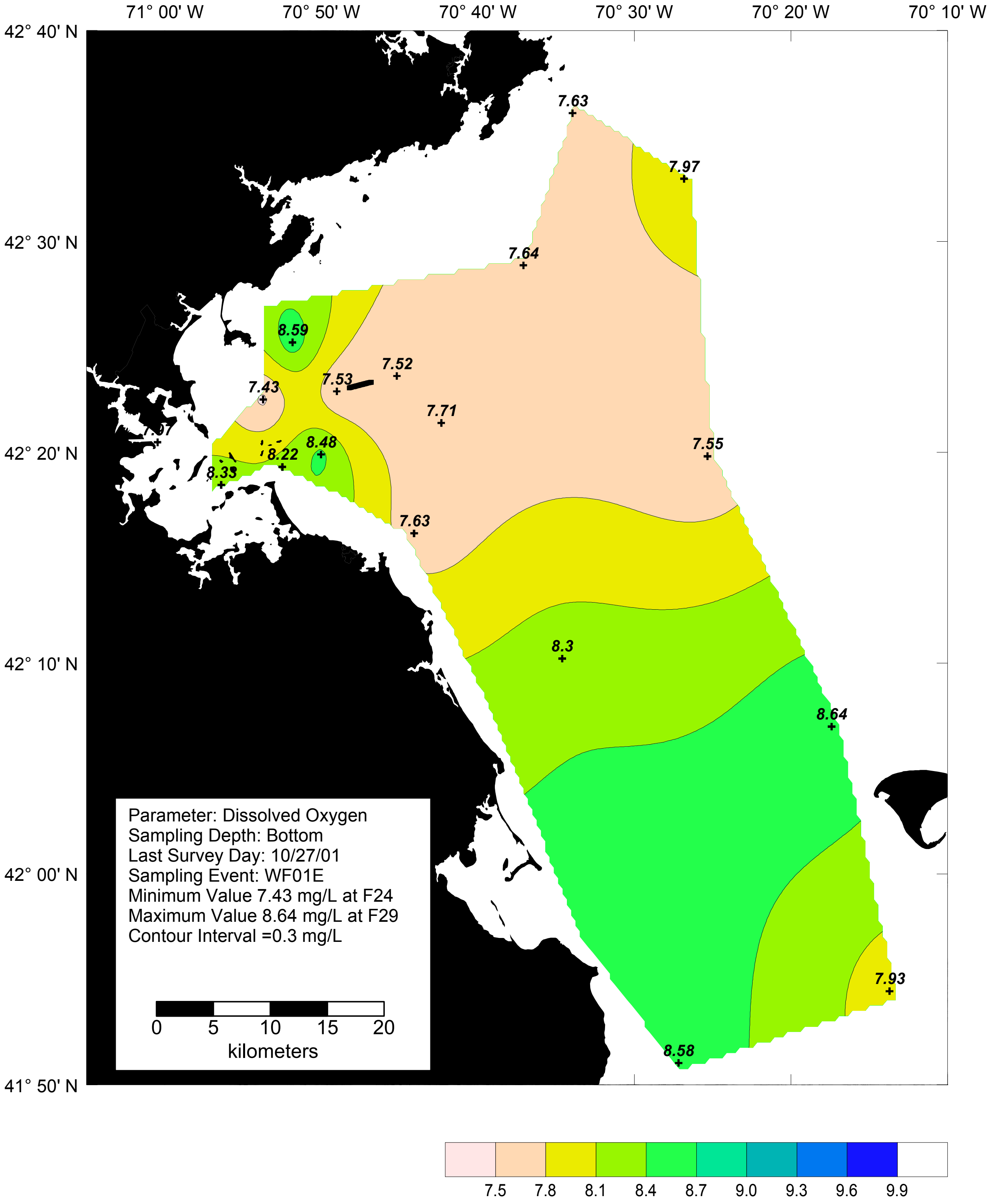



**Figure 4-43. Dissolved Oxygen Bottom Contour (Bottle Data) in the Farfield Survey WF01E (Oct 01)**

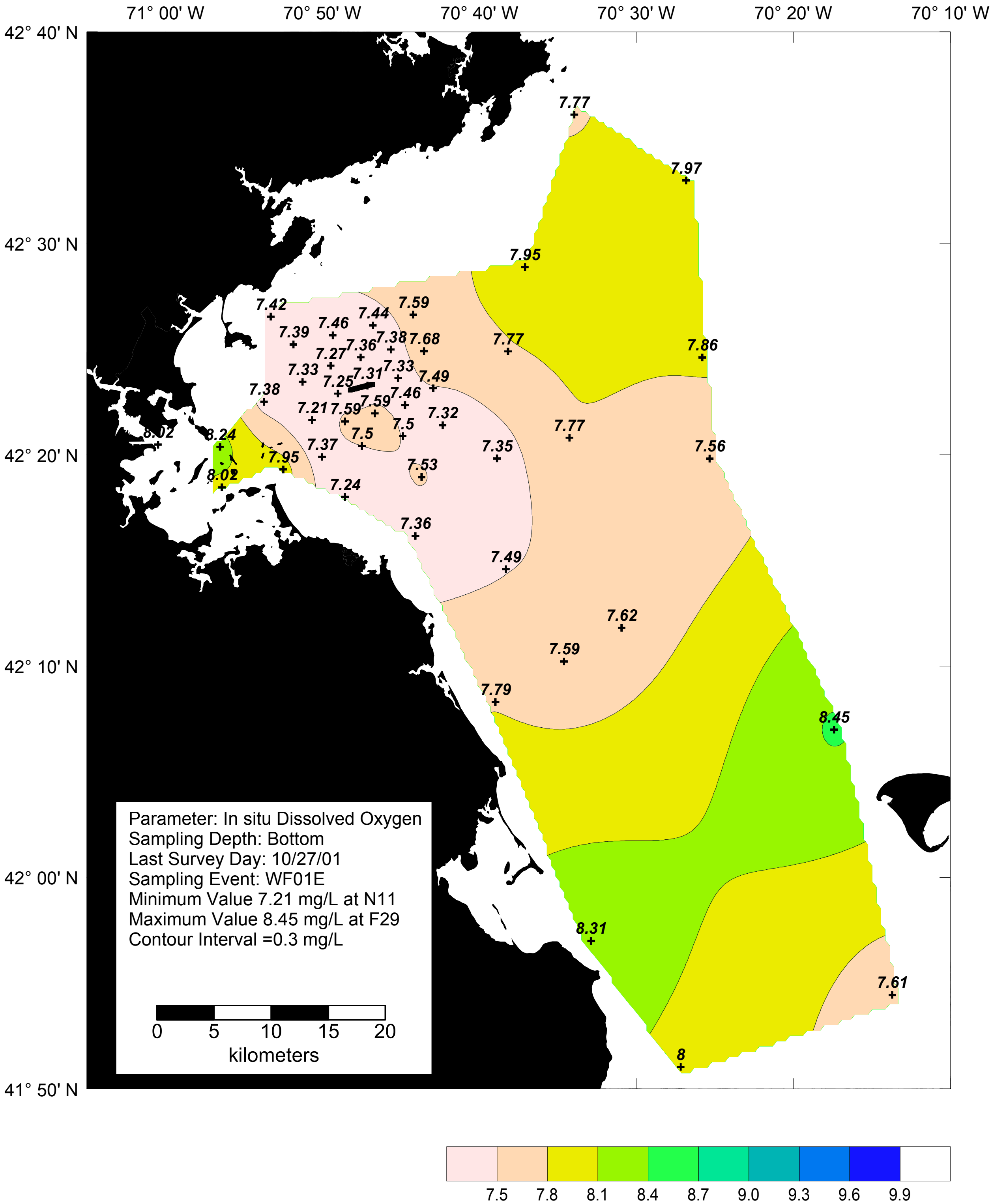
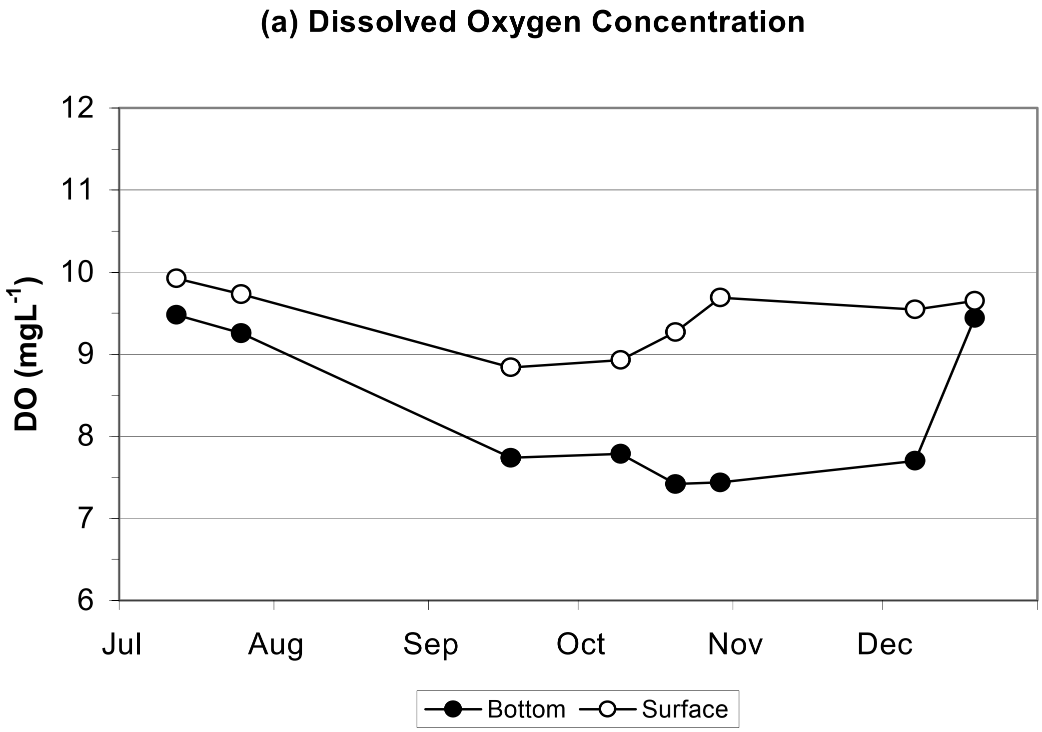



**Figure 4-44. Dissolved Oxygen Bottom Contour (In situ Data) in the Farfield Survey WF01E (Oct 01)**



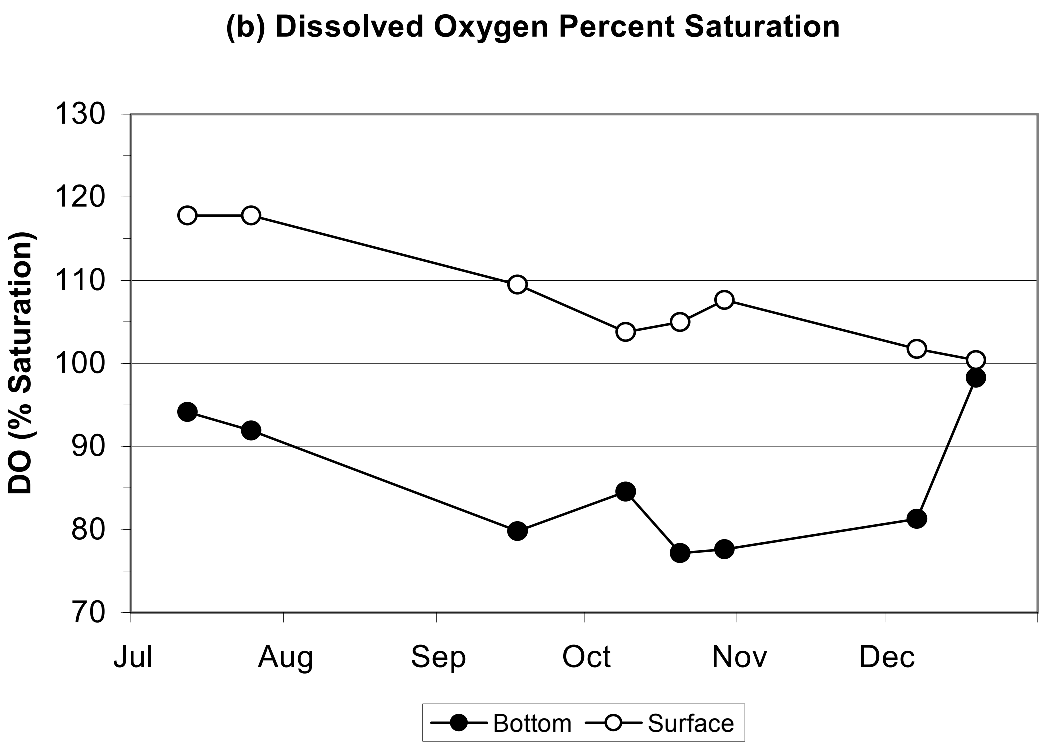




**Figure 4-45. Time Series of Average Surface and Bottom (a) DO Concentration and (b) Percentage Saturation in the Nearfield**

Note: All *in situ* DO data were suspect for both August surveys (WN01A and WF01B)

# 5.0 PRODUCTIVITY, RESPIRATION, AND PLANKTON RESULTS

## 5.1 Productivity

Production measurements were taken at two nearfield stations (N04 and N18) and one farfield station (F23) near the entrance of Boston Harbor. All three stations were sampled on August 29 (WF01B) and October 20 (WF01E). Stations N04 and N18 were also sampled on July 12 (WN018), July 25 (WN019), August 9 (WN01A), September 17 (WN01C), October 9 (WN01D), October 29 (WN01F), December 7 (WN01G), and December 19 (WN01H). Samples were collected at five depths throughout the euphotic zone. Production was determined by measuring $^{14}C$ at varying light intensities as summarized below and in Appendix A.

In addition to samples collected from the water column, productivity calculations also utilized light attenuation data from a CTD-mounted 4π sensor, and incident light time-series data from a 2π irradiance sensor located on Deer Island, MA. After collection, productivity samples were returned to the Marine Ecosystems Research Laboratory (MERL) in Rhode Island and incubated in temperature controlled incubators. The resulting photosynthesis versus light intensity (P-I) curves (Figure 5-1 and comprehensively in Appendix E) were used, in combination with light attenuation and incident light information, to determine hourly production at 15-min intervals throughout the day for each sampling depth.

For this semi-annual report, areal production (mg C $m^{-2}$ $d^{-1}$) and depth-averaged chlorophyll-specific production (mg C mg $Chl^{-1}$ $d^{-1}$) are presented (Figures 5-2 and 5-3). Areal productions are determined by integrating measured productivity over the depth interval. Chlorophyll-specific productivity for each depth was determined by normalizing productivity by measured chlorophyll *a*. Productivity, chlorophyll-specific productivity and chlorophyll *a* for each depth are also presented as contour plots (Figures 5-4 to 5-9).

### 5.1.1 Areal Production

Areal production at the nearfield stations (N04 and N18) displayed a similar pattern throughout the semi-annual sampling period (Figure 5-2). Areal production at the two sites was > 890 mg C $m^{-2}$ $d^{-1}$ during the initial survey in July. Production at station N18 was somewhat higher at this time (~1400 mg C $m^{-2}$ $d^{-1}$) compared with station N04 (~ 900 mg C $m^{-2}$ $d^{-1}$). Values at both stations decreased by late July to 667 mg C $m^{-2}$ $d^{-1}$ at N18 and 312 mg C $m^{-2}$ $d^{-1}$ at N04. By early August, productivity increased somewhat to about 740 mg C $m^{-2}$ $d^{-1}$ at both stations. At station N04 productivity declined slightly from late August through mid September. During the same period, station N18 was characterized by a minor productivity peak in late August (~1500 mg C $m^{-2}$ $d^{-1}$) followed by a slight decline (~1000 mg C $m^{-2}$ $d^{-1}$) in mid September. Following this decline, production increased at both stations to a major productivity peak (~ 2700 mg C $m^{-2}$ $d^{-1}$) in early October. Productivity declined somewhat during the following 2 sampling events in October reaching lower levels at N18 than N04. The maximum annual productivity for each station was observed during early December (WN01G) with peak values >3250 mg C $m^{-2}$ $d^{-1}$ at both stations. Productivity at station N18 (and N16) is generally greater than that observed at station N04. However, during this semi-annual reporting period productivity at station N18 was consistently higher than N04 from July through September. From October through December productivity was higher at station N04. The 2001 fall peaks in productivity observed at both stations during October and December were markedly similar. Productivity at station F23, at the outer edge of Boston Harbor, was greater than the nearfield sites in late August and lower in October. In 1995 and 1996 the highest areal productivity values were recorded at station F23. Beginning in 1997, the highest areal productivity measurements over the annual cycle were recorded in the nearfield region rather than Boston Harbor.

At both stations the timing and the magnitude of the early and late fall blooms in production were similar. Productivity has typically been greater at station N18 during the initial fall bloom and greater at station N04 during the second bloom. The peak productivity at station N04 during this semi-annual period occurred December 7 with a production of 3264 mg C $m^{-2}$ $d^{-1}$. Station N18 reached its maximum value (3250 C $m^{-2}$ $d^{-1}$) on the same date. Both stations were also characterized by elevated production (2670 - 2714 mg C $m^{-2}$ $d^{-1}$) on October 9. Production minima for this reporting period were observed at station N04 (312 mg C $m^{-2}$ $d^{-1}$) on July 25 and station N18 (667 C $m^{-2}$ $d^{-1}$) on December 19, the final survey of the year.

At the Boston Harbor productivity/respiration station (F23), areal production (1999 mg C $m^{-2}$ $d^{-1}$) during the August survey was the highest productivity observed at the three monitoring stations for that sampling event. Areal production at station F23 decreased to 703 mg C $m^{-2}$ $d^{-1}$ by October 20 and was lower than the measured production at the nearfield stations. The production data at station F23 are in agreement with the chlorophyll data. During WF01B, chlorophyll values were high and productivity was high. Lower chlorophyll values during WF01E were associated with decreased productivity levels.

Areal production in 2001 followed patterns typically observed in prior years. Distinct fall phytoplankton blooms were observed as increases in production at both nearfield stations during the sampling period (Figure 5-2). In general, nearfield stations are characterized by the occurrence of a fall bloom. The fall blooms observed at nearfield stations in 1995-2000 generally reached values of 1600 to 4900 mg C $m^{-2}$ $d^{-1}$, with blooms typically lasting 3-4 weeks. The bloom in 2001 reached peak values of >3250 mg C $m^{-2}$ $d^{-1}$ at both stations and occurred from October 20 through December 7. The secondary peak in fall productivity occurred later than usual. The patterns observed at the nearfield sites were generally consistent with those observed during prior years although the timing of events varied. The late fall increase in productivity at station N04 relative to N18 has not been observed in prior years. The delay in peak productivity and the increase in station N04 production relative to station N18 will be discussed in more detail in the 2001 annual report.

Station N18 is the productivity station closest to the outfall and any effects from sewage-derived nutrients would be detected here first. Areal productivity at station N18 did not increased in 2001 either relative to prior years or compared with station N04 during the current year.

### 5.1.2 Chlorophyll-Specific Production

Depth-averaged chlorophyll-specific production displayed a similar pattern but different magnitudes at both nearfield sites (N04 and N18) during the initial three surveys (WN018 – WN01A) for the current semi-annual reporting cycle (Figure 5-3). At station N04, depth-averaged chlorophyll-specific production rates were relatively constant from mid-July through December and consistently lower than values at station N18. At station N18, depth-averaged chlorophyll-specific production increased from late-July to a seasonal maximum in late summer, and then decreased to relatively stable values throughout the fall period (21.7 – 23.8 mg C mg Chl $a^{-1}$ $d^{-1}$). Seasonal maxima were reached during September (WN01C) at station N18 with a recorded value of 58.4 mg C mg Chl $a^{-1}$ $d^{-1}$ and during August (WN01A) at station N04 with a peak of 17.2 mg C mg Chl $a^{-1}$ $d^{-1}$. The seasonal minima (5.2 mg C mg Chl $a^{-1}$ $d^{-1}$ at station N04 and 18.4 mg C mg Chl $a^{-1}$ $d^{-1}$ at station N18) were reached during the late July survey (WN019). Chlorophyll-specific rates in the harbor were closer to the values reported for station N04 than station N18 during the sample period (Figure 5-3).

The distribution of depth-averaged chlorophyll-specific production indicates that the efficiency of production was high relative to the amount of biomass present at station N18 on August 29 and September 17. At both stations N04 and N18 the peak chlorophyll-specific production occurred during the summer rather than during the late-fall phytoplankton bloom. The previously observed fall production peaks appeared to be an effect of high biomass levels rather than actual increases in specific production rates. Variation in chlorophyll-specific production is an approximate measure for the efficiency of production and frequently reflects nutrient conditions at the sampling sites. The consistently higher depth-averaged chlorophyll-specific production at N18 most likely reflects the greater availability of nutrients at this station during this sampling period. The late summer peak in chlorophyll-specific productivity at station N18 may reflect an increase in nutrients related to destratification of the water column or may be related to species composition. The efficiency of productivity at station N04 was relatively constant throughout this semi-annual reporting period.

### 5.1.3 Production at Specified Depths

The spatial and temporal distribution of production, chlorophyll and chlorophyll-specific production on a volumetric basis were summarized by showing contoured values over the sampling period (Figures 5-4 to 5-9). Chlorophyll-specific productions (daily production normalized to chlorophyll concentration at each depth) were calculated to compare production with chlorophyll concentrations. Chlorophyll-specific production can be used as an indicator of the optimal conditions necessary for photosynthesis.

The volumetric data reveal that the fall peaks in areal productivity (October 9 and December 7) reported during WN01D and WN01G at station N04 were concentrated in the upper 10 m of the water column (Figure 5-4). Areal productivity at station N18 reached bloom values (>100 mg C $m^{-3}$ $d^{-1}$) on the same dates with high values observed from the surface to the bottom sample on October 9, at depths down to 20 m (Figure 5-5). At station N18, the annual productivity peak occurred on December 7 (WN01G) and was distributed throughout the upper 15 m of the water column with values from the surface to mid-bottom depth samples ranging from ~120 - 220 mg C $m^{-3}$ $d^{-1}$ (Figure 5-5). At the two-nearfield stations, productions were elevated from late summer through the fall bloom peak period. For station N04, the highest production value observed (~220 mg C $m^{-3}$ $d^{-1}$) occurred at the surface (1.43 m) on October 20. For station N18, the highest production value observed (~220 mg C $m^{-3}$ $d^{-1}$) occurred on December 7 and was recorded at the mid-surface depth (5.2 m). Peak production values tended to be correlated with the occurrence of the highest chlorophyll *a* measurements (Figures 5-6 and 5-7).

High productivity (>100 mg C $m^{-3}$ $d^{-1}$) at station N18 commonly occurred at depths >15 m throughout the late summer-fall period, with values greater than 60 mg C $m^{-3}$ $d^{-1}$ occurring to depths of 20 m. At station N18 both the mean and maximum productivity at the bottom depths were greater than prior years. A similar increase in bottom productivity was not noted at station N04. At station N04 productivity greater than 100 mg C $m^{-3}$ $d^{-1}$ was generally confined to the upper 10 m of the water column. The productivity pattern at specified depths observed in 2001 was similar to that observed in prior years for station N04. At station N04 productivity >10 mg $m^{-3}$ $d^{-1}$ was rarely observed at depths >20 m. At station N18 productivity as high as 133 mg C $m^{-3}$ $d^{-1}$ was recorded from depths of 20 m with values > 60 mg C $m^{-3}$ $d^{-1}$ frequently observed here. Productivity in the harbor was largely restricted to the upper 10 m of the water column. The relatively high bottom water productivity that was measured at station N18 will be examined in more detail in the 2001 annual report.

Chlorophyll-specific production (mg C mg $Chl^{-1}$ $d^{-1}$) exhibited a much more uniform behavior (Figures 5-8 and 5-9) compared to depth-specific daily productivity, particularly at station N04. Elevated chlorophyll-specific production was primarily concentrated in the upper portions of the water column throughout the sampling period at N04. At station N18, elevated chlorophyll-specific production was generally confined to the summer and early-fall periods and extended from the surface to the mid-depths. Peak chlorophyll-specific productions occurred during the September surveys (WN01C) at station N18 and during late October (WF01E) at station N04. In general, the efficiency of photosynthesis decreased both with depth (station N04 and N18) and as the season progressed (station N18). Chlorophyll-specific production did not increase at either station in late fall indicating that the December production peak primarily reflects higher phytoplankton biomass (measured as total chlorophyll *a*) at this time.

## 5.2 Respiration

Respiration measurements were made at the same nearfield (N04 and N18) and farfield (F23) stations as productivity and at an additional station in Stellwagen Basin (F19). All four stations were sampled during each of the combined farfield/nearfield surveys and stations N04 and N18 were also sampled during the eight nearfield surveys. Respiration samples were collected from three depths (surface, mid-depth, and bottom) and were incubated in the dark at *in situ* temperatures for 8±1 days.

Both respiration (in units of $\mu MO_2hr^{-1}$) and carbon-specific respiration ($\mu MO_2\mu MC^{-1}hr^{-1}$) waters are presented in the following sections. Carbon-specific respiration was calculated by normalizing respiration rates to the coincident particulate organic carbon (POC) concentrations. Carbon-specific respiration rates provide a relative indication of the biological availability (labile) of the particulate organic material for microbial degradation.

### 5.2.1 Water Column Respiration

Due to the timing of the surveys, the farfield stations were only sampled twice (WF01B and WF01E). Evaluation of the temporal trends is therefore focused on the nearfield area where data are available over the entire July to December time period.

Nearfield respiration rates reached a maximum for this time period during the early July survey with rates of >0.2 $\mu MO_2hr^{-1}$ in the surface waters at both stations N04 and N18 (Figure 5-10). Lower rates were observed in the mid-depth waters 0.11-0.13 $\mu MO_2hr^{-1}$. Respiration rates were low (<0.05 $\mu MO_2hr^{-1}$) in the bottom waters at station N04 in July and early August. Bottom water rates at station N18 decreased from 0.1 $\mu MO_2hr^{-1}$ in early July to 0.05 $\mu MO_2hr^{-1}$ in August. This decrease was coincident with decreasing rates in both surface and mid-depth waters at both stations. By mid-August (WF01B), respiration rates had increased to 0.1 – 0.15 $\mu MO_2hr^{-1}$ over the entire water column at both nearfield stations. Rates were somewhat higher at Boston Harbor station F23 ranging from 0.13 – 0.16 $\mu MO_2hr^{-1}$, but the highest respiration rates for the time period were observed at Stellwagen Basin station F19 (Figure 5-11). The maximum rate of 0.25 $\mu MO_2hr^{-1}$ was measured in station F19 mid-depth waters and elevated respiration (0.17 $\mu MO_2hr^{-1}$) was also observed for the surface water.

Respiration rates at station N18 increased slightly from August thru early October. At station N04 there was a small decrease in rates in September (WN01C) with a subsequent increase in surface and bottom water rates in early October. Relatively low respiration rates ($\leq 0.1 \mu MO_2hr^{-1}$) were observed across the nearfield in mid October (WF01E). Similarly low rates were observed at station F19 and in the mid-depth and bottom waters at station F23. Surface water respiration reached a survey maximum of 0.18 $\mu MO_2hr^{-1}$ at Boston Harbor station F23. Nearfield respiration rates for surface and mid-depth waters increased to 0.15 $\mu MO_2hr^{-1}$ by late October coincident with increasing production associated with the late fall bloom. Rates remained elevated and increased in bottom waters at station N18 in early December with the continuation of the late fall/early winter bloom. Rates were lower (<0.1 $\mu MO_2hr^{-1}$) at station N04 in early December and were low at both stations by the late December survey. The magnitude and trends in the respiration rate data for the nearfield stations were similar to previous years for this time period.

The rate of respiration is dependent upon a number of factors including the effect of temperature on metabolic processes and the availability of organic carbon. During the second half of 2001, these parameters were not as closely correlated as might be expected (Figure 5-12). Although the data in these plots are from all 4 stations, there was no substantial improvement in the relationships at the individual stations. The relationship between respiration and temperature is often represented by an exponential fit, but in this case the data were best fit by the linear regression presented ($R^2$=0.26 vs. 0.24; Figure 5-12a). Although the R2 is relatively low, the relationship between respiration and temperature is significant ($P<0.01$). This is not the case for respiration and particulate organic carbon (POC; $P=0.08$; Figure 5-12b) and the relationship between respiration and dissolved organic carbon (DOC) was even worse (data not shown, $P>0.3$). The lack of a relationship between respiration and organic carbon concentrations may have more to do with the make-up (recalcitrant vs. labile) of the organic carbon. This influence of organic carbon composition is discussed further in the next section. A more detailed review of factors affecting respiration rates will be conducted in the 2001 annual water column report.

### 5.2.2 Carbon-Specific Respiration

Normalizing respiration by carbon attempts to account for the effect variations in the size of the POC pool have on respiration. Differences in carbon-specific respiration result from variations in the quality of the available particulate organic material or from environmental conditions such as temperature. Particulate organic material that is more easily degraded (more labile) will result in higher carbon-specific respiration. In general, newly produced organic material is the most labile. Water temperature is the main physical characteristic that controls the rate of microbial oxidation of organic material – the lower the temperature the lower the rate of oxidation. When stratified conditions exist, the productive, warmer surface and/or mid-depth waters usually exhibit higher carbon-specific respiration rates and bottom waters have lower carbon-specific respiration rates due to both lower water temperature and lower substrate quality due to the degradation of particulate organic material during sinking.

POC concentrations were high in the mid-depth water at station N18 in early July (62 µM) coincident with elevated chlorophyll concentrations (see Figure 4-38). Lower values were measured for station N18 surface and bottom waters and no data were available for station N04 during this survey (Figure 5-13). By late July, POC concentrations had decreased at station N18 to 23 – 27 µM and were <23 µM at station N04. POC concentrations remained relatively low at all 4 respiration stations from August through October (Figures 5-13 and 5-14). There was a large decrease in POC concentration in the mid-depth and bottom waters at station N18 from early to mid October, which was coincident with a decrease in respiration. From mid-October to early December there was a large increase in POC concentrations at the nearfield stations that resulted from the late fall/early winter bloom. In early December, POC concentrations at station N18 ranged from 55 – 60 over the entire water column and reached a maximum for this time period of 88µM for the mid-depth at station N04. Surface water POC concentration was also high (44 µM) at station N04. These high POC concentrations were coincident with the productivity and chlorophyll maxima observed at both stations during this survey. By late December, POC concentrations had decreased to ~20 µM across the nearfield.

Carbon-specific respiration rates reached a maximum in the nearfield at station N04 in late August with a rate of 0.018 $\mu MO_2 \mu MC^{-1}hr^{-1}$ in the bottom water (Figure 5-15). The bottom water rate was also high at station N04 in mid October (0.011 $\mu MO_2 \mu MC^{-1}hr^{-1}$). Otherwise carbon-specific respiration rates were generally low (≤0.005 $\mu MO_2 \mu MC^{-1}hr^{-1}$) and relatively constant over the entire July to December time period. At station F23, carbon-specific respiration rates remained relatively low throughout this time period with a decrease in mid-depth and bottom waters and an increase in surface water from August to October (Figure 5-16). At the Stellwagen Basin station F19, carbon-specific respiration rates were high in the mid-depth and bottom waters in August (0.014 and 0.011 $\mu MO_2 \mu MC^{-1} hr^{-1}$, respectively) and decreased by October over the entire water column.

Given the high chlorophyll concentrations and production rates at stations N04 and N18 and the increase in POC concentrations by early December that resulted, it might have been expected that carbon-specific respiration would increase with the increased availability of newly produced, labile organic carbon. The sharp decrease in temperatures, however, resulted in lower respiration rates offsetting whatever the impact may have been due to the availability of more labile organic carbon in December. It has been suggested that dissolved organic carbon may provide additional insight into trends in respiration, but as noted in the previous section, there was no significant relationship between DOC and respiration during July – December 2001. The calculation of carbon-specific respiration rates based on DOC and also TOC (total organic carbon) provided no additional insight into the trends in respiration for this time period. The importance of DOC as a pool of available organic carbon will be included in the more detailed analysis of respiration for the 2001 annual report.

## 5.3 Plankton Results

Plankton samples were collected on each of the ten surveys conducted from July to December 2001. Phytoplankton and zooplankton samples were collected at two stations (N04 and N18) during each nearfield survey and at 13 farfield plus the two nearfield stations (total = 15) during the farfield surveys. Phytoplankton samples included both whole-water and 20 µm-mesh screened samples, from the surface and mid-depth. The mid-depth sample corresponds to the subsurface chlorophyll maximum if one is present. Zooplankton samples were collected by vertical/oblique tows with 102 µm-mesh nets. Methods of sample collection and analyses are detailed in Albro *et al*. (2002).

In this section, the seasonal trends in plankton abundance and regional characteristics of the plankton assemblages are evaluated. Total abundance and relative abundance of major taxonomic group are presented for each phytoplankton and zooplankton community. Tables in the appendices provide data on cell densities and relative abundance for all dominant plankton species (>5% abundance): Appendix F – whole water phytoplankton, Appendix G – 20-µm screened phytoplankton, and Appendix H – zooplankton.

### 5.3.1 Phytoplankton

#### 5.3.1.1 Seasonal Trends in Total Phytoplankton Abundance

Total phytoplankton abundance in nearfield whole water samples (surface and mid-depth) varied from 0.99 – 4.49 x $10^6$ cells $L^{-1}$ in July, 0.60-2.60 x $10^6$ cells $L^{-1}$ in August, and declined to 0.78-1.67 x $10^6$ cells $L^{-1}$ in mid September (Table 5-1). There were only two samples during the four July - September surveys with an abundance > 3.0 x $10^6$ cells $L^{-1}$ (N18, surface and mid depth WN019) and they were primarily composed of microflagellates (Figures 5-17a and 5-18a). Phytoplankton abundance increased slightly by October (1.01 – 3.26 x $10^6$ cells $L^{-1}$), and microflagellates remained the dominant component through late October (Figures 5-17 and 5-18). Phytoplankton abundance declined to lower levels (0.49-2.09 x $10^6$ cells $L^{-1}$) in December. The decrease in phytoplankton abundance from fall to early winter is typical for this time of year, but in comparison to most years the late fall and early winter abundance levels were relatively high. Levels of > $10^6$ cells $L^{-1}$ at station N04 (mostly centric diatoms) during WF01E, WN01F, and WN01G (Figs. 5-16c and 5-17c), and at station N18 during WN01G (Figs. 5-16a and 5-17a) were coincident with not only high chlorophyll concentrations (see Section 4.2.2) but also with the peak primary production (> 3,500 mg C $m^{-3}$ $d^{-1}$), for this semiannual period (see Section 5.1.1).

Total phytoplankton abundance in farfield whole water samples (Table 5-1) was similar for August (0.67 – 3.84 x $10^6$ cells $L^{-1}$) and October (0.81 – 2.62 x $10^6$ cells $L^{-1}$). As in the nearfield, total abundance generally declined from August to October (Figures 5-19 and 5-20).

Total abundance of dinoflagellates and silicoflagellates in 20 µm-mesh-screened water samples were considerably lower than those recorded for total phytoplankton in whole-water samples, due to the screening technique which selects for larger, albeit rarer cells. Screened phytoplankton abundance fluctuated widely (385 – 15,314 cells $L^{-1}$) from July through December (Table 5-2).

**Table 5-1. Nearfield and Farfield Averages and Ranges of Abundance ($10^6$ Cells $L^{-1}$) of Whole-Water Phytoplankton**

| Survey | Dates (2001) | Nearfield Mean | Nearfield Range | Farfield Mean | Farfield Range |
|---|---|---|---|---|---|
| WN018 | 7/12 | 1.64 | 0.99-2.22 | -- | -- |
| WN019 | 7/25 | 3.29 | 1.73-4.49 | -- | -- |
| WN01A | 8/09 | 1.65 | 0.80-2.18 | -- | -- |
| WF01B | 8/27-8/30 | 1.62 | 0.60-2.60 | 2.11 | 0.67-3.84 |
| WN01C | 9/17 | 1.29 | 0.78-1.67 | -- | -- |
| WN01D | 10/09 | 1.84 | 1.01-2.42 | -- | -- |
| WF01E | 10/19-22, 25,26 | 1.82 | 1.20-2.24 | 1.50 | 0.81-2.61 |
| WN01F | 10/29 | 2.44 | 1.35-3.26 | -- | -- |
| WN01G | 12/07 | 1.67 | 1.23-2.09 | -- | -- |
| WN01H | 12/19 | 0.66 | 0.49-0.78 | -- | -- |

**Table 5-2. Nearfield and Farfield Average and Ranges of Abundance (Cells $L^{-1}$) for >20 µM-Screened Dinoflagellates**

| Survey | Dates (2001) | Nearfield Mean | Nearfield Range | Farfield Mean | Farfield Range |
|---|---|---|---|---|---|
| WN018 | 7/12 | 7294 | 2063-15314 | -- | -- |
| WN019 | 7/25 | 1310 | 649-1843 | -- | -- |
| WN01A | 8/09 | 999 | 455-1482 | -- | -- |
| WF01B | 8/27-8/30 | 632 | 385-858 | 689 | 58-4128 |
| WN01C | 9/17 | 593 | 260-1155 | -- | -- |
| WN01D | 10/09 | 1977 | 1350-2525 | -- | -- |
| WF01E | 10/19-22, 25,26 | 1309 | 680-2000 | 774 | 70-2793 |
| WN01F | 10/29 | 1475 | 783-2025 | -- | -- |
| WN01G | 12/07 | 2623 | 1400-4030 | -- | -- |
| WN01H | 12/19 | 2896 | 1840-3955 | -- | -- |

#### 5.3.1.2 Nearfield Phytoplankton Community Structure

***Whole-Water Phytoplankton*** – In early July (WN018), nearfield whole-water phytoplankton assemblages from both depths (Figures 5-17 and 5-18) were dominated by unidentified microflagellates (> 50% of total abundance). Cryptomonads, chain-forming centric diatoms (*Dactyliosolen fragilissimus, Guinardia delicatula, Leptocylindrus minimus*), the pennate diatom

*Cylindrotheca closterium*, and a dinoflagellate of the genus *Gymnodinium* were subdominants (5-16% of total abundance). By mid July (WN019), the dominance of microflagellates (> 50-76% of total abundance) continued, with subdominant contributions (5-10%) from cryptomonads and *Gymnodinium* sp. However, at the sub-surface chlorophyll maximum depth, these were joined by the pennate diatoms *Cylindrotheca closterium* and *Pseudo-nitzschia pseudodelicatissima* (this species has been systematically listed in the bi-monthly reports in combination with *P. delicatissima*, which is another species); the latter at an abundance of 0.278 x $10^6$ cells $L^{-1}$, comprising 16.1% to total cells.

In August (WN01A and WN01B) the dominance of <10 µm microflagellates (68-86% of total cells) continued in the nearfield, but there were subdominant contributions (5-10%) from cryptomonads, the diatoms *Leptocylindrus danicus* and *Dactyliosolen fragilissimus*, and *Gymnodinium* sp. In mid-September (WN01C), microflagellates continued to comprise 53-60% of total cells, with cryptomonads, *Leptocylindrus danicus*, small centric diatoms <10 µm in longest dimension and Gymnodinium sp. comprising 5.2-11.3% of total abundance. By early October (WN01D), microflagellates continued to dominate abundance (62-64%), with contributions of cryptomonads, *Dactyliosolen fragilissimus*, small centric diatoms <10 µm in longest dimension and *Gymnodinium* spp. comprising 5-17% of total abundance.

During early October (WF01E), microflagellates had declined to 17-73% of total cells, with greater proportions of cryptomonads (up to 17% of total abundance), small centric diatoms < 10 µm in diameter, *Gymnodinium* sp., and the chain-forming diatoms *Leptocylindrus danicus* (up to 24%) and *Leptocylindrus minimus* (up to 36%). The dominance by microflagellates (58-69%), with additional contributions from cryptomonads (10-15%), *Leptocylindrus danicus* (5-13%) and small centric diatoms (5-8%) and *Gymnodinium* sp. (up to 7%) continued during late October (WN01F). By early December (WN01G) microflagellate dominance had declined (20-47% of total cells), with a mixture of subdominants such as cryptomonads (5-6%), small centric diatoms <10 µm in longest dimension (up to 8%), a small species of the diatom genus *Thalassiosira* with cells 10-20 µm in longest dimension (7%), and other diatoms such as *Guinardia delicatula* (up to 5%), *Leptocylindrus danicus* (5-20%), *Skeletonema costatum* (5-17%), *Thalassiosira nordenskioldii* (6.9-7.6%). The high chlorophyll levels recorded for late November to early December by SeaWiFS (Appendix I) was coincident with the increased abundance of these large chain-forming diatoms (Figures 5-17 and 5-18) and elevated production rates (see Section 5.1.1). By late December (WN01H) dominance by microflagellates (48-57%), was shared with cryptomonads (up to 12%), *Dactyliosolen fragilissimus* (8-19%), *Leptocylindrus danicus* (8-11%), and small centric diatoms <10 µm in longest dimension (6%).

***Screened Phytoplankton*** – The dinoflagellates *Ceratium tripos*, *Ceratium fusus, Ceratium longipes* and other members of this genus were the overwhelming dominants in nearfield screened phytoplankton samples from July and early August (WN018, WN019, and WN01A). In late August (WF01B), additional contributions came from other dinoflagellates such as *Dinophysis norvegica* and, at the chlorophyll-maximum depth at Station N16, an unidentified athecate dinoflagellate that comprised 30.5% of total abundance. Dominance by the *Ceratium* trio continued in September (WN01C) and early October (WN01D), with additional contributions from dinoflagellates such as *Prorocentrum micans, P. minimum, Protoperidinium bipes, Scrippsiella trochoidea,* unidentified athecate and thecate dinoflagellates, and the silicoflagellate *Dictyocha fibula*. By late October (WF01E) there was a shift to lesser dominance by *Ceratium fusus* (6-22%) and *C. tripos* (up to 17%), with greater contributions by the dinoflagellates *Prorocentrum micans* (up to 20%), *Gymnodinium* sp. (27% at the chlorophyll maximum depth at Station N04), unidentified thecate and athecate dinoflagellates, and the silicoflagellate *Dictyocha fibula* (14-76%). *Ceratium fusus* (7-23%) and *C. tripos* (9-23%) continued to proportionally decline relative to *P. micans* (up to 61%) and *D. fibula* (up to 56%) near the end of October (WN01F). From early December (WN01G), varying proportions of

*C. fusus* (up to 58%), *C. lineatum* (up to 5%), *P. micans* (up to 61%) and *D. fibula* (up to 36%) gave way by mid-December (WN01H), to declining proportions of *C. fusus* (6-14%), *C. lineatum* (7-13%), and *C. tripos* (up to 7%) compared to greatly increased proportions (64-75%) of *P. micans*.

#### 5.3.1.3 Farfield Phytoplankton Assemblages

***Whole-Water Phytoplankton*** - During WF01B in August, most farfield station assemblages were dominated at both depths by unidentified microflagellates, with lesser contributions by cryptomonads and centric diatoms (Figure 5-19). However, relative proportions of these taxa varied with location. At stations in Boston Harbor (F23, F30, F31), microflagellates only comprised approximately 36-48% of total cells, and cryptomonads comprised only 9-20%. Combinations of small centric diatoms <10µm in size (5-8%), and other centrics such as *Dactyliosolen fragilissimus* (up to 12-13%), *Leptocylindrus danicus* (up to 8-19%), and *Skeletonema costatum* (up to 29% at station F30) shared dominance with the microflagellates and cryptomonads (Figs. 5-16a, b). Similarly, at coastal stations (F13, F24, F25), microflagellates (40-75%), cryptomonads (10-16%), small centrics (up to 6-9%), *Dactyliosolen fragilissimus* (up to 12%), and Leptocylindrus *danicus* (5-25%) shared dominance. Patterns were different for offshore (F06, F22), boundary (F26, F27), and Cape Cod (F01, F02) stations. There, microflagellates were dominant comprising 72-84%, 67-77%, and 66-76%, respectively, and cryptomonads comprised 7-13%, 10-14%, and 8-12%, respectively, at offshore, boundary and Cape Cod stations (Figs. 5-19a, b).

During WF01E in October, most farfield stations were dominated by unidentified microflagellates and cryptomonads <10 µm in size, with small centric diatoms <10µm in size present in subdominant abundance (Figure 5-20a, b). However, as in August, there were regional differences in the relative proportions of these taxa. At stations in Boston Harbor (F23, F30, F31), microflagellates only comprised approximately 46-57% of total cells, and cryptomonads comprised only 10-19%. Combinations of small centric diatoms <10µm in size (up to 5-8%), and other centrics such as *Leptocylindrus danicus* (5-16%), *L. minimus* and *Skeletonema costatum* (each up to 6%) shared dominance. Similarly, at coastal stations (F13, F24, F25), microflagellates (35-61%), cryptomonads (up to 13%), small centrics (up to 10%), and Leptocylindrus *danicus* (5-35%), and *L. minimus* (up to 8%) shared dominance. Patterns were different for offshore (F06, F22), boundary (F26, F27), and Cape Cod (F01, F02) stations. There, microflagellates were dominant comprising approximately 60-68%, 58-72%, and 63-75%, respectively, and cryptomonads comprised 5-13%, 10-13%, and 8-14%, respectively, at offshore, boundary and Cape Cod stations (Figs. 5-20a, b). Contributions of diatoms such as *Dactyliosolen fragilissimus, Leptocylindrus danicus, L. minimus, Guinardia delicatula,* small centrics <10µm in size, and dinoflagellates of the genus *Gymnodinium* never exceeded 10%.

***Screened Phytoplankton*** – During late August (WF01B), 20-µm screened phytoplankton samples from the farfield were similar to nearfield assemblages, dominated by the dinoflagellates *Ceratium. fusus* (up to 52%), *C. longipes* (up to 80%), *C. tripos* (up to 100%) and other members of the genus *Ceratium* (up to 11%), with lesser contributions at various stations by the dinoflagellate *Prorocentrum micans* (up to 48% in Boston Harbor, < 6% elsewhere), *P. minimum* (up to 8% in Boston Harbor), *Scrippsiella trochoidea* (< 16%), *Gymnodinium* sp. (< 10%), and various other identified thecate (up to 25%) and athecate (up to 32%) dinoflagellates.

During late October (WF01E), 20-µm screened phytoplankton samples from the farfield were similar to nearfield assemblages, dominated by the dinoflagellates *Ceratium fusus* (up to 22%), *C. longipes* (up to 12%), *C. tripos* (up to 26%) and other members of the genus *Ceratium* (up to 11%), with lesser contributions at various stations by the dinoflagellate *Prorocentrum micans* (up to 60% in Boston Harbor, < 52% elsewhere), *P. minimum* (up to 8% in Boston Harbor), *Scrippsiella trochoidea* (< 16%), *Gymnodinium* sp. (< 10%), and various other identified thecate (up to 40%) and athecate (up to 19%) dinoflagellates. The silicoflagellates *Dictyocha fibula* and *Distephanus speculum* also comprised up to 76% and up to 9%, respectively, of total abundance at various stations, particularly outside Boston Harbor. Within the harbor, abundances of these silicoflagellates were < 11% of total cells.

#### 5.3.1.4 Nuisance Algae

There were no confirmed blooms of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during July – December 2001. Some species that have caused harmful blooms in different seasons in previous years, such as *Phaeocystis pouchetii* (early spring), were unrecorded during this period. *Alexandrium* spp. were recorded only twice in screened water samples, both in July: at station N04 at the chlorophyll maximum depth during survey WN018 there were 2.6 cells $l^{-1}$, and at station N18 at the chlorophyll maximum depth during survey WN019, there were 2.5 cells $l^{-1}$. These values were well below the threshold limit for Alexandrium, which is 100 cells $l^{-1}$ for any single nearfield sample (Table 5-3). Other non-toxic species whose blooms have caused anoxic events elsewhere, such as *Ceratium tripos* were routinely present, but not at abundances approaching those previously associated with anoxia.

Potentially toxic species of the diatom genus *Pseudo-nitzschia* were present at many stations from July through December, but usually in extremely low abundances. *Pseudo-nitzschia pseudodelicatissima* was present in all 6 whole-water phytoplankton samples from the July-August surveys WN018, WN019, and WN01A. At the chlorophyll maximum depth at station N04 during survey WN019, there were 278 x $10^3$ cells $l^{-1}$ of *P. pseudodelicatissima*. Otherwise, values for this species during these surveys was ≤ 71.5 x $10^3$ cells $l^{-1}$. During survey WF01B in late August, *P. pseudodelicatissima* was recorded for 27 of 30 samples, at a range of 0.2-14.8 x $10^3$ cells $l^{-1}$. *Pseudo-nitzschia pseudodelicatissima* was present in all but 6 of 48 samples from the September-December surveys WN01C, WN01D, WF01E, WN01F, WN01G, and WN01H, at abundance levels of 0.5-23.9 x $10^3$ cells $l^{-1}$. *Pseudo-nitzschia pseudodelicatissima* has been associated with domoic acid toxicity in the sea (Hasle and Syvertsen, 1997). It is unclear whether abundances of *P. pseudodelicatissima* within the threshold levels should cause alarm, when these thresholds were originally established for what is identified with light microscopy as *Pseudo-nitzschia "pungens*." This designation can include both non-toxic *P. pungens* as well as the identical-appearing (at least with light microscopy) domoic-acid-producing species *P. multiseries*. Resolving the species identifications of these two species requires scanning electron microscopy. MWRA and HOM3 scientists are currently reviewing the inclusion of additional Pseudo-nitzschia species in the MWRA threshold calculation.

Nominal *Pseudo-nitzschia pungens* were recorded throughout the July-December period. There were two July-August records for *P. pungens*: an abundance of 1.4 x $10^3$ cells $l^{-1}$at the chlorophyll maximum depth at station N04 during WN019, and 1.1 x $10^3$ cells $l^{-1}$at the surface at station N16 during WF01B. However, during the September-December surveys, *P. pungens* was recorded for all but 9 of 48 samples, at abundance levels of 0.4-35.9 x $10^3$ cells $l^{-1}$. The maximum value of 35.9 x $10^3$ cells $l^{-1}$ was the only record that exceeded the nearfield autumn threshold for *P. pungens* of 24.6 x $10^3$ cells $l^{-1}$. However, the autumn 2001 nearfield mean for *P. pungens* was 5.9 x $10^3$ cells $l^{-1}$, which is the value that is compared against the threshold (Table 5-3).

**Table 5-3. Contingency plan nearfield threshold values for Nuisance Algae**

| Location | Parameter | Time Period | Caution Level | Value Observed (2001) |
|---|---|---|---|---|
| Nearfield | *Phaeocystis pouchetii* | Summer Mean | 334 cells $l^{-1}$ | none |
| | | Autumn Mean | 2,370 cells $l^{-1}$ | none |
| Nearfield | *Pseudo-nitzchia pungens* | Summer Mean | 38,000 cells $l^{-1}$ | 1,400 cells $l^{-1}$ |
| | | Autumn Mean | 24,600 cells $l^{-1}$ | 5,900 cells $l^{-1}$ |
| Nearfield | *Alexandrium tamarense* | Any nearfield screened sample | 100 cells $l^{-1}$ | 2.6 cells $l^{-1}$ |

## 5.3.2 Zooplankton

### 5.3.2.1 Seasonal Trends in Total Zooplankton Abundance

Total zooplankton abundance at nearfield stations was at normal seasonal high levels in July (15.3-45.4 x $10^3$ animals $m^{-3}$). This increased to even higher levels in early August (47.3-50.5 x $10^3$ animals $m^{-3}$), with annual maximum levels (40.6-104.2 x $10^3$ animals $m^{-3}$) in late August (Table 5-4). This pattern of annual zooplankton maximum abundance in August is typical. Zooplankton abundance decreased in early September to maximum levels less than half of the August maxima, and remained low (< 43.1 x $10^3$ animals $m^{-3}$) through December (Figure 5-21).

Zooplankton abundance in Boston Harbor reached unprecedented low levels during October 2000 due to decimation of zooplankton populations by ctenophore predation. This did not occur in fall of 2001. Disintegrated tissue of the ctenophore *Mnemiopsis leidyi* was absent from samples collected during this period.

**Table 5-4. Nearfield and Farfield Average and Ranges of Abundance ($10^3$ Animals $m^{-3}$) for Zooplankton**

| Survey | Dates (2001) | Nearfield Mean | Nearfield Range | Farfield Mean | Farfield Range |
|---|---|---|---|---|---|
| WN018 | 7/12 | 24.7 | 19.7-29.6 | -- | -- |
| WN019 | 7/25 | 30.3 | 15.3-45.4 | -- | -- |
| WN01A | 8/09 | 48.9 | 47.3-50.5 | -- | -- |
| WF01B | 8/27-8/30 | 63.1 | 40.6-104.2 | 56.9 | 23.9-79.4 |
| WN01C | 9/17 | 34.0 | 31.2-36.8 | -- | -- |
| WN01D | 10/09 | 16.2 | 14.7-17.7 | -- | -- |
| WF01E | 10/19-22, 25,26 | 26.3 | 20.1-33.1 | 31.4 | 9.1-76.7 |
| WN01F | 10/29 | 28.8 | 22.9-34.7 | -- | -- |
| WN01G | 12/07 | 33.3 | 23.5-43.1 | -- | -- |
| WN01H | 12/19 | 23.2 | 15.8-30.5 | -- | -- |

#### 5.3.2.2 Nearfield Zooplankton Community Structure

In July (WN018 and WN019) nearfield zooplankton assemblages were dominated by copepod nauplii, *Oithona similis* copepodites and females, with subdominant contributions by copepodites of the genera *Pseudocalanus, Temora*, and *Centropages* (Figure 5-21). In August (WN01A and WF01B), the nearfield zooplankton assemblages continued to be dominated by copepod nauplii, and females and copepodites of *Oithona similis* with lesser contributions by copepodites of *Pseudocalanus* sp. The extremely high abundance (104,236 animals $m^{-3}$) at station N04 during survey WF01B was not due to a spike in the abundance of any particular taxon. Rather, it was simply due to higher overall zooplankton abundance at this station. Comparisons of percentages of total abundance for dominant taxa at the three nearfield stations during this survey revealed that each had approximately the same relative abundances; copepod nauplii were 20-26%, *Oithona similis* copepodites were 44-47%, *O. similis* females were 8-13%, and *Pseudocalanus* copepodites were 5-8% of total abundance, respectively, at the nearfield stations. Also, at 4 other stations in various regions of the farfield (F01, F06, F26, and F31), total zooplankton abundances were between 70-80 x $10^3$ animals $m^{-3}$, approaching that at station N04 (Figure 5-22a). In September (WN01C) and October (WN01D, WF01E, and WN01F), dominance of copepod nauplii, and females and copepodites of *Oithona similis* continued, with lesser contributions from *Centropages* copepodites and in late October, bivalve veligers. In December (WN01G and WN01H), the dominance of copepod nauplii and *Oithona similis* was shared to a lesser extent by copepodites of the genus *Pseudocalanus*.

#### 5.3.2.3 Farfield Zooplankton Assemblages

At farfield stations during survey WF01B in late August, copepod nauplii were dominants (16-37%), with subdominant contributions at various stations outside Boston Harbor by females (5-11%) and copepodites (33-52%) *Oithona similis,* and other species recorded for the nearfield (Figure 5-22). Adults and copepodites of *Acartia* spp. comprised up to 27% of the assemblage in Boston Harbor, and *Centropages hamatus* copepodites and adults comprised 20% of the assemblage at station F23 in Boston Harbor. During WF01E in late October, copepod nauplii were dominant everywhere (10-57%), and outside the harbor *Oithona similis* copepodites (11-37%) and females (up to 8%), Pseudocalanus copepodites (up to 14%) and bivalve veligers (up to 29%) were abundant at most farfield stations. *Acartia* spp. adults and copepodites were again abundant in Boston Harbor (up to 19%).

In summary, zooplankton assemblages during the second half of 2001 were comprised of taxa recorded for this time of year in previous baseline monitoring years.

## 5.4 Summary of Water Column Biological Results

- Areal production at the nearfield stations (N04 and N18) displayed a similar pattern throughout the semi-annual sampling period. Productivity at N18 tended to be somewhat higher than N04 during July through mid-September; productivity at N04 tended to be somewhat higher than N18 from October through December. The elevated productivity at N04 versus N18 is a change from previous years.
- The maximum annual productivity for each station was observed in early December with peak values >3250 mg C $m^{-2}$ $d^{-1}$ at both stations and was correlated with the occurrence of the highest chlorophyll *a* measurements. This was relatively late for the peak production to be observed in the nearfield in comparison to previous years.
- At station N04, chlorophyll-specific areal production rates were relatively constant from mid-July through December and consistently lower than values at station N18.
- At station N18 both the mean and maximum productivity at the bottom depths were greater than prior years. A similar increase in bottom productivity was not noted at station N04
- Nearfield respiration rates reached a maximum for this time period during the early July survey with rates reaching 0.22 $\mu MO_2hr^{-1}$ in the surface waters at station N18. Farfield respiration rates reached a maximum of 0.25 $\mu MO_2hr^{-1}$ at mid-depth at station F19. Rates were relatively low for the remainder of the period.
- There was no coincident increase in respiration rates in the nearfield associated with the elevated chlorophyll concentrations and high production rates observed at these stations during the late fall/early winter bloom. This was likely due to the lower water temperatures.
- POC concentration at mid-depth was high at station N18 (62 µM) in early July. Maximum POC concentrations were reached in early December – 88 µM at mid-depth at station N04 and 55-60 µM over the entire water column and station N18. The increase in POC concentrations was coincident with the increase in productivity and chlorophyll concentrations during the early December survey.
- Carbon-specific respiration rates reached a maximum in late August in the nearfield at station N04 with a rate of 0.018 $\mu MO_2\mu MC^{-1}hr^{-1}$ in the bottom water and in the farfield at the Stellwagen Basin station F19 in the mid-depth water (0.014 $\mu MO_2\mu MC^{-1}hr^{-1}$).
- Total phytoplankton abundances in the whole water samples were maximal in late July, decreasing somewhat through August- October, and declined to lower levels in December.
- The whole water phytoplankton assemblage was dominated by unidentified microflagellates, with cryptomonads and the chain-forming centric diatoms *Leptocylindrus danicus*, *Dactyliosolen fragilissimus, Guinardia delicatula*, and other diatoms and dinoflagellates as subdominants.
- The >20-µm screened dinoflagellate assemblage was dominated from July through October by *Ceratium tripos, C. longipes* and *C. fusus* as in previous years, with a transition to dominance by *Prorocentrum micans* in December.
- There were no confirmed blooms of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during July – December 2001, although the potentially-toxic diatom *Pseudo-nitzschia pseudodelicatissima* was present and frequently abundant throughout much of the area

from July through December. This species is not currently included in the calculation of the *Pseudo-nitzschia "pungens"* threshold.

- Zooplankton abundance increased through July to annual maximum levels in late August, progressively declining through September and October, into December.

- Zooplankton abundance was, as usual, dominated by copepod nauplii and adults and copepodites of the small copepods *Oithona similis*, and copepodites of *Pseudocalanus* and *Centropages* sp., with lesser contributions, at some stations, by meroplankters such as bivalve veligers and, in Boston Harbor, *Acartia* spp. copepodites and adults.

**WN018** **Station N18**

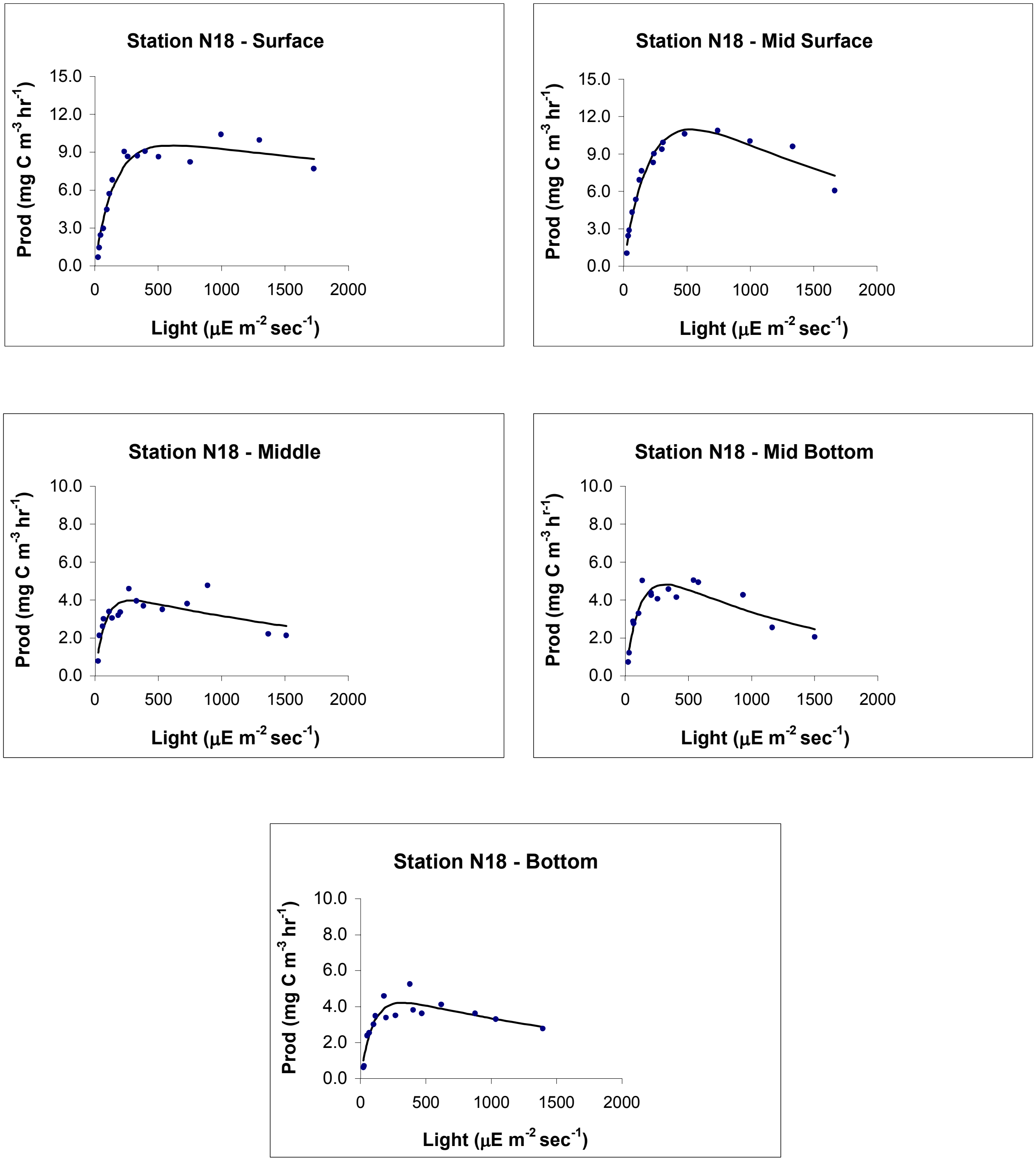



**Figure 5-1. An example photosynthesis-irradiance curve from station N18 collected in July 2001**

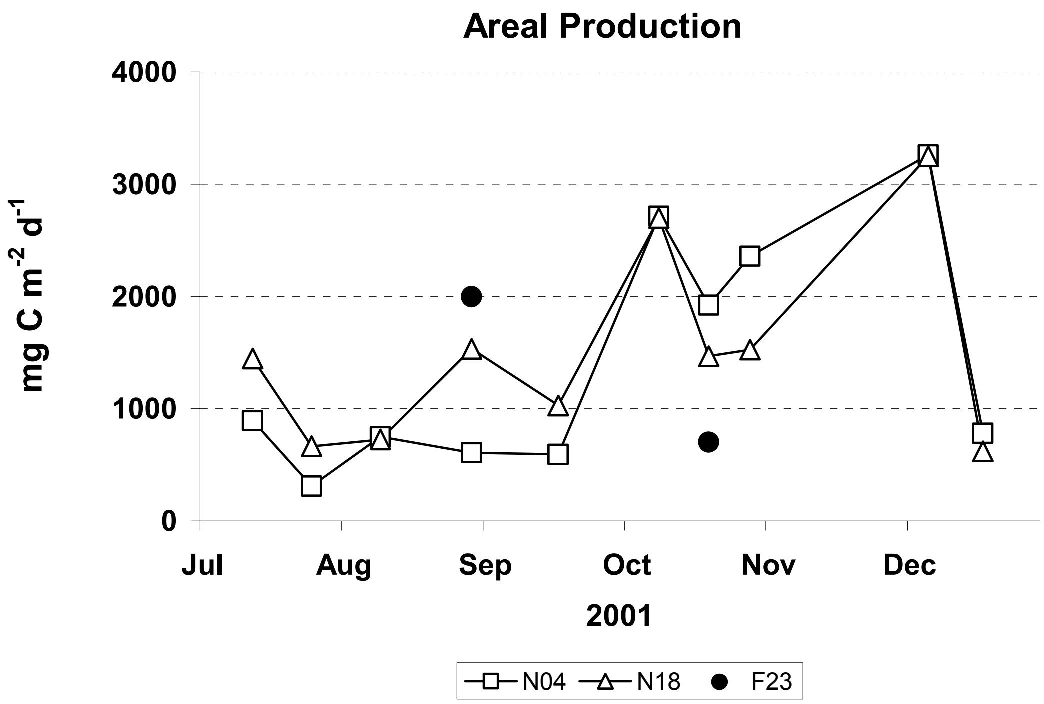



**Figure 5-2. Time-series of areal production (mg C $m^{-2}$ $d^{-1}$) for stations N04, N18 and F23**

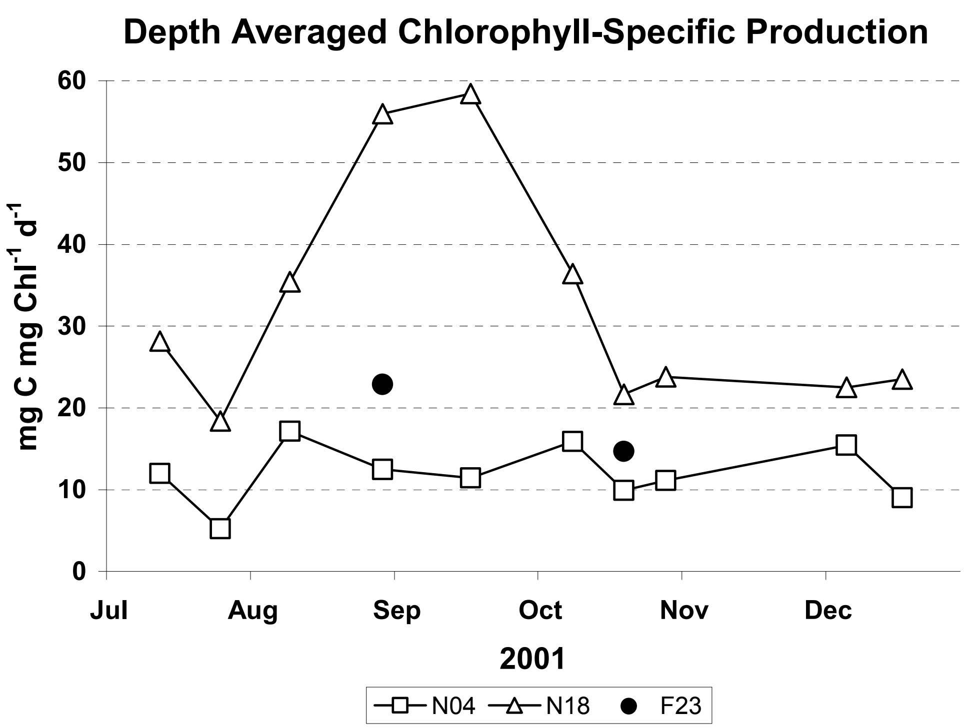



**Figure 5-3. Time-series of depth-averaged chlorophyll-specific production (mg C mg $Chl^{-1}$ $d^{-1}$) for stations N04, N18 and F23**

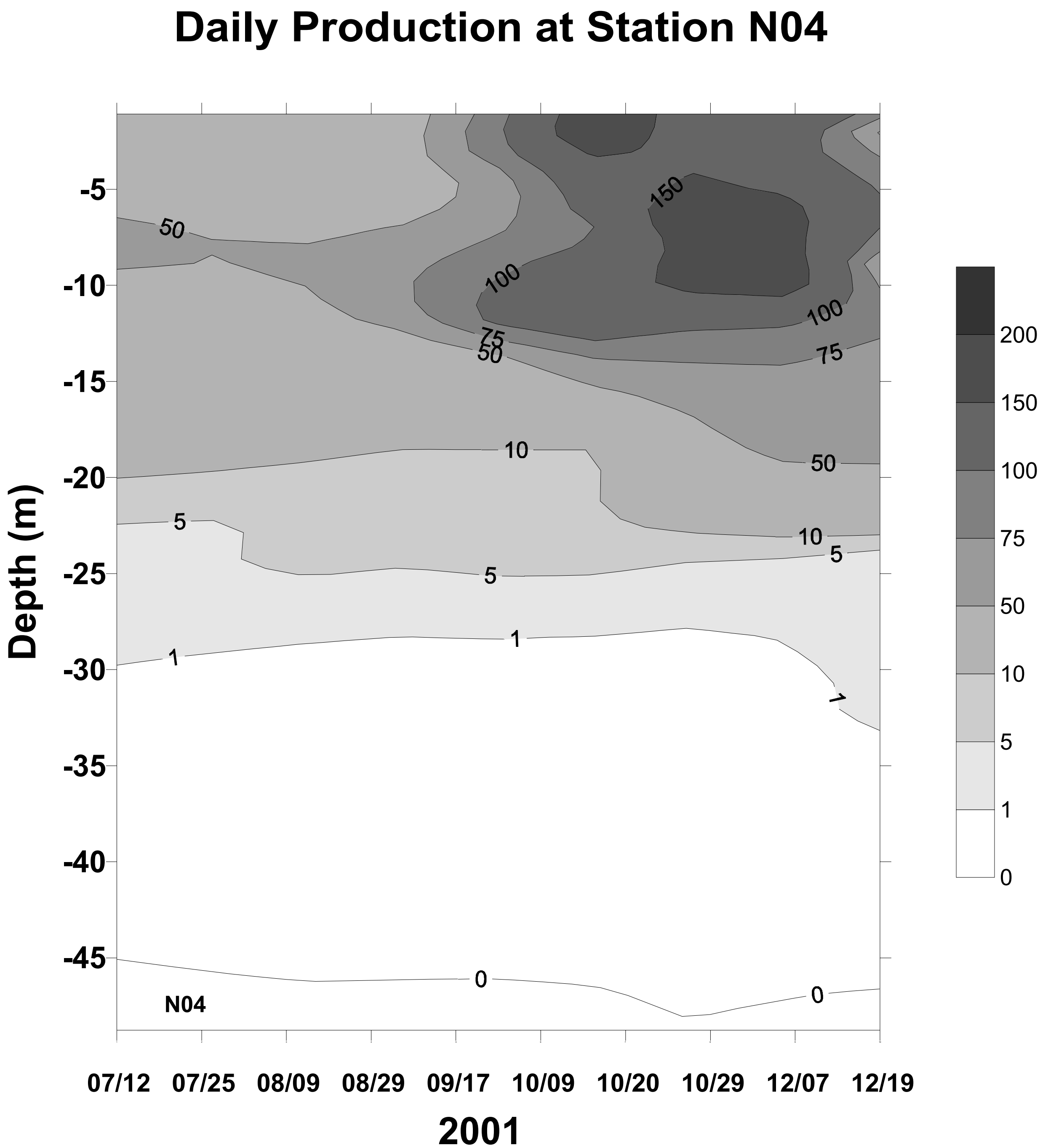



**Figure 5-4**. **Time series of contoured daily production ($mgCm^{-3}d^{-1}$) over depth at station N04**

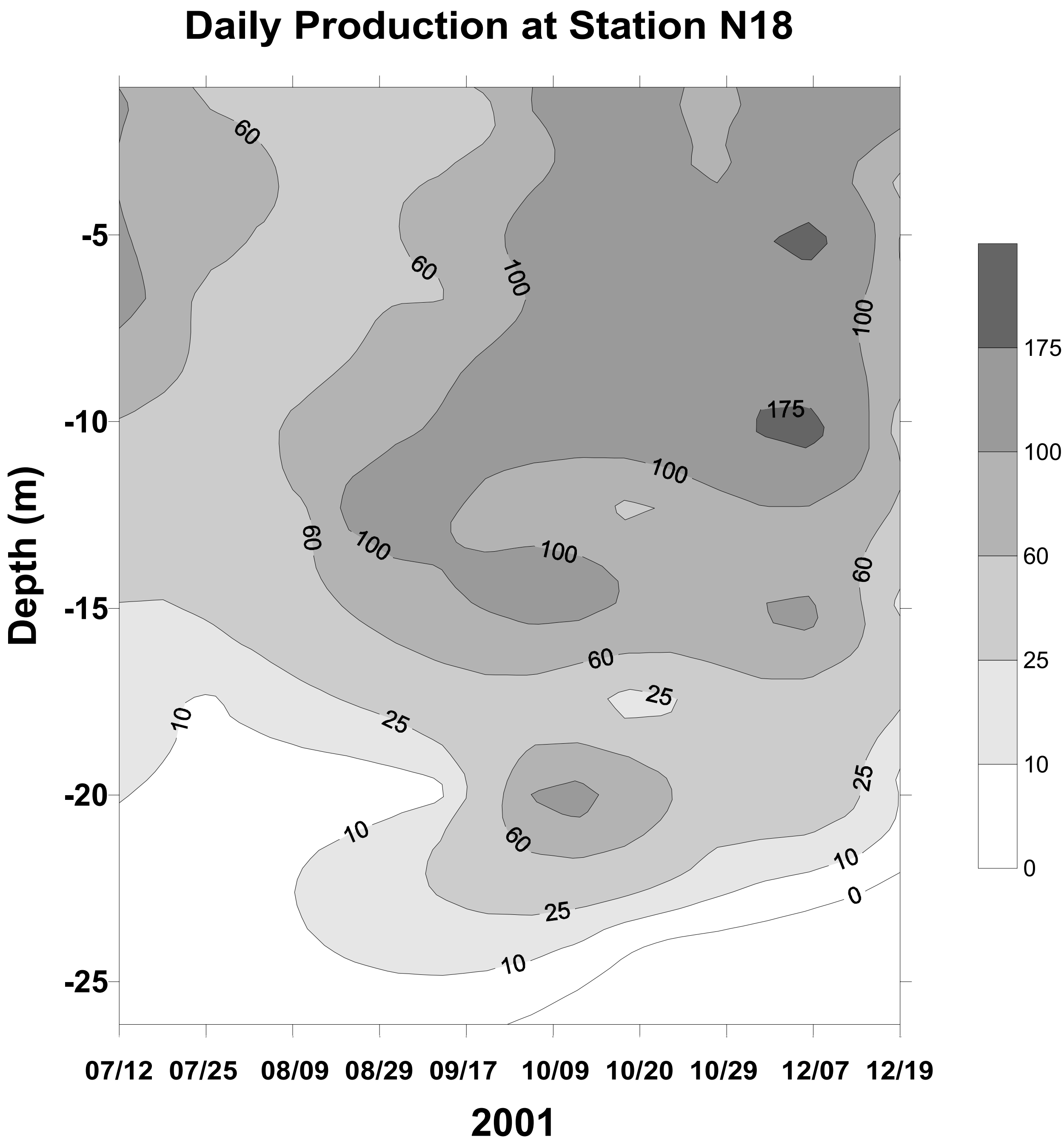



**Figure 5-5. Time series of contoured daily production ($mgCm^{-3}d^{-1}$) over depth at station N18**

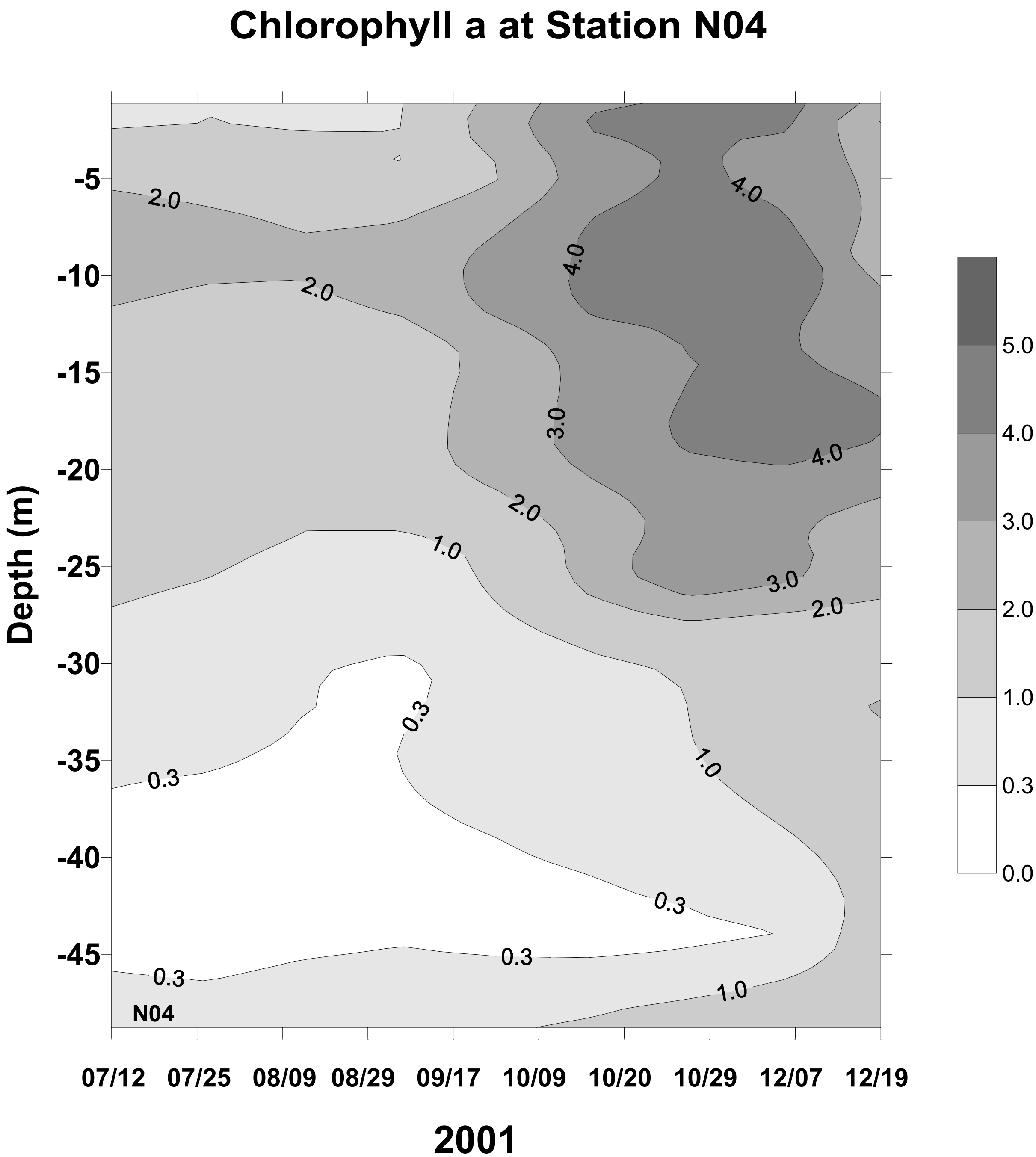



**Figure 5-6. Time series of contoured chlorophyll concentration ($\mu g\ L^{-1}$) over depth at station N04**

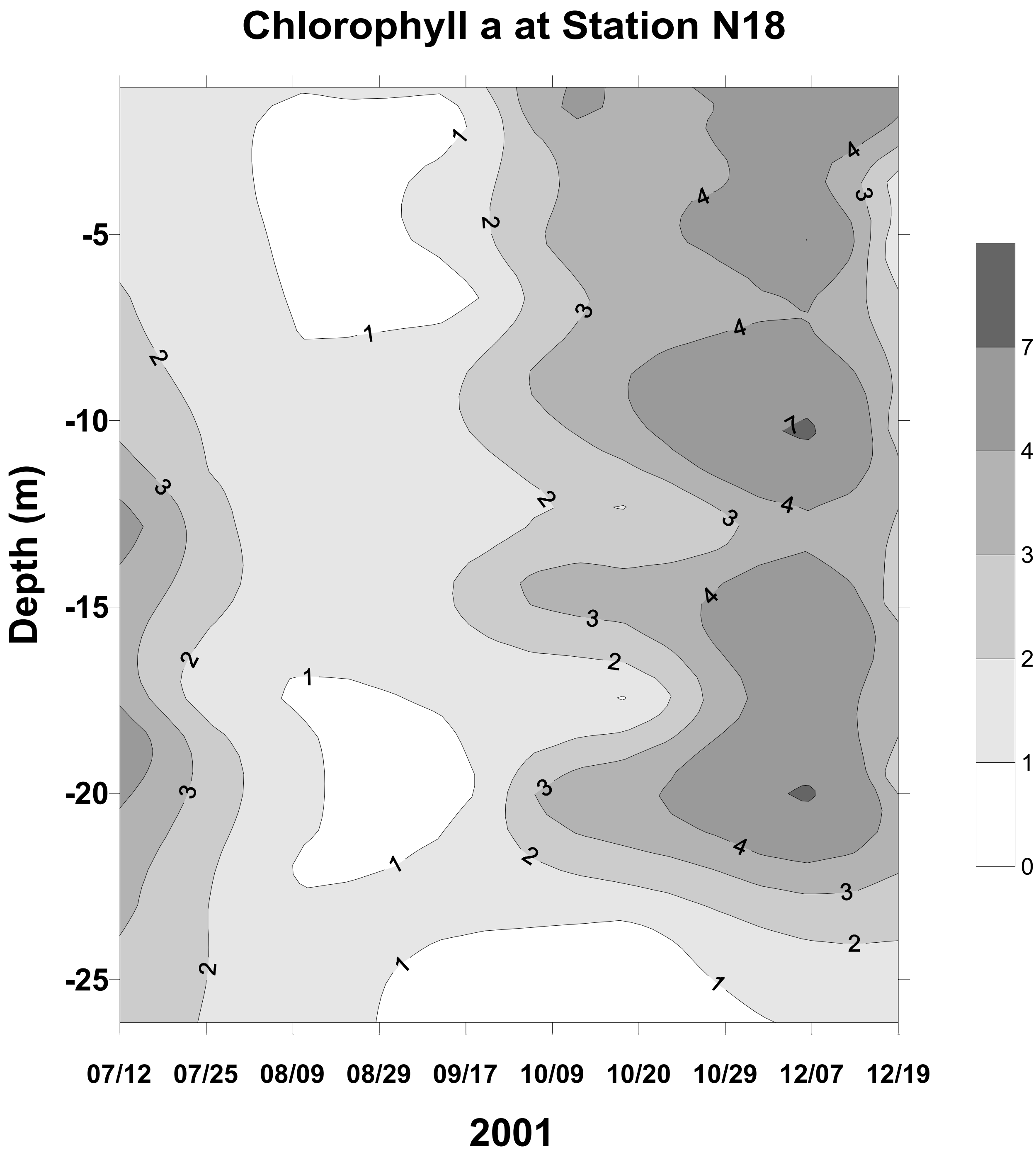



**Figure 5-7. Time series of contoured chlorophyll concentration (μg $L^{-1}$) over depth at station N18**

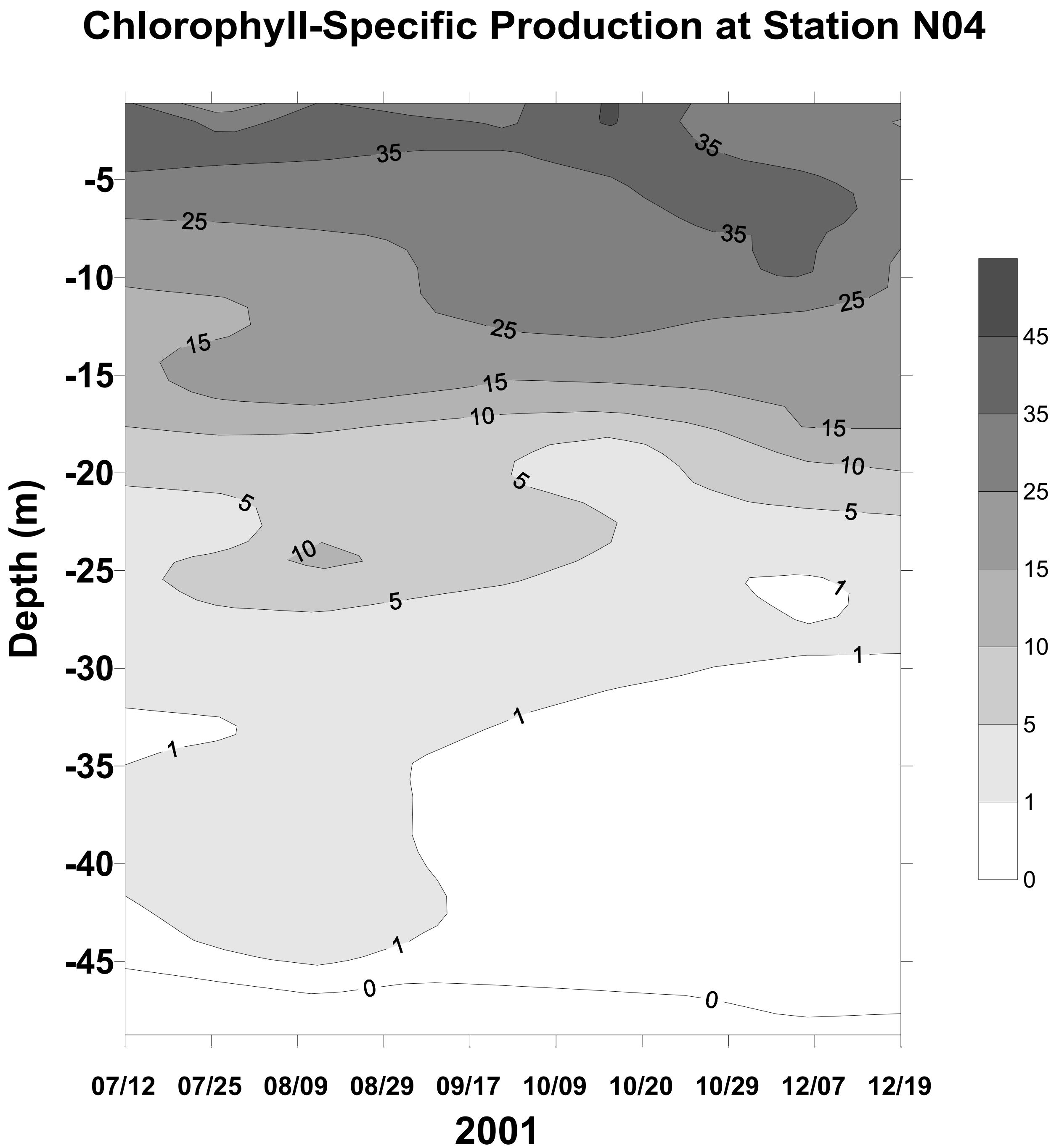



**Figure 5-8. Time series of contoured chlorophyll-specific production (mg Cmg $Chl^{-1}d^{-1}$) over depth at station N04**

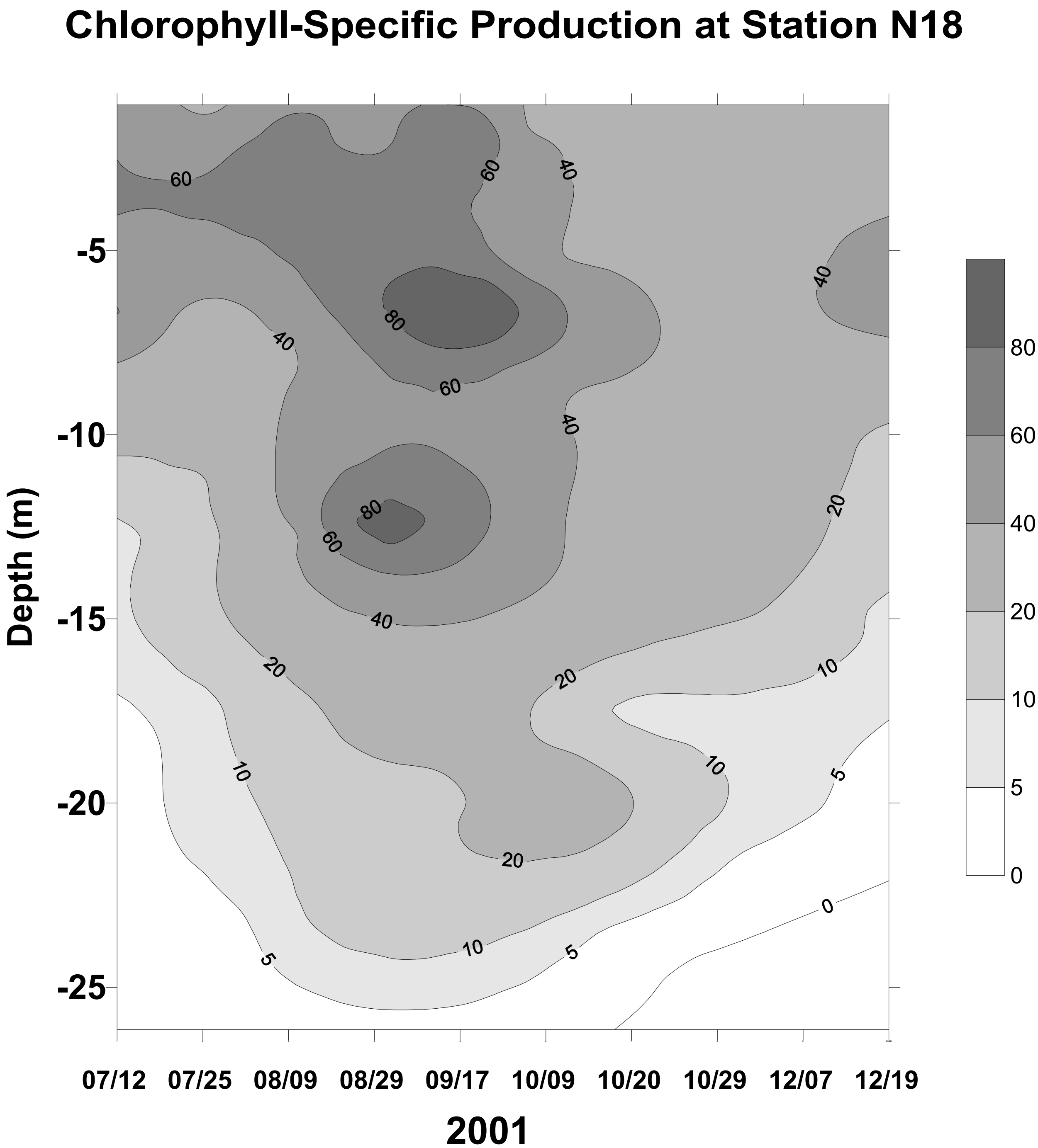
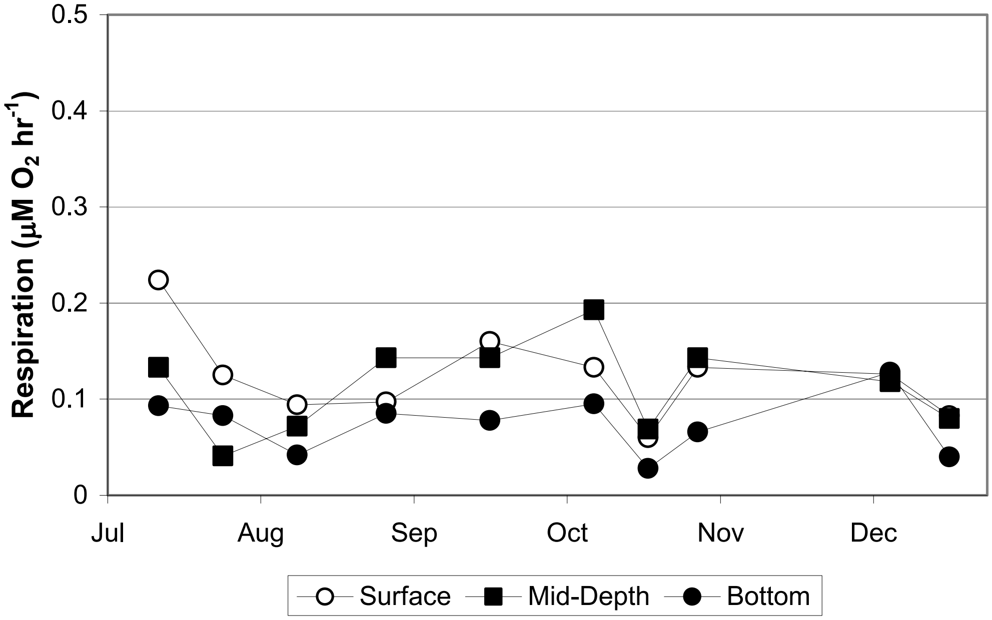



**Figure 5-9. Time series of contoured chlorophyll-specific production (mg Cmg Chl$^{-1}$d$^{-1}$) over depth at station N18**

**(a) Station N18**




**(b) Station N04**

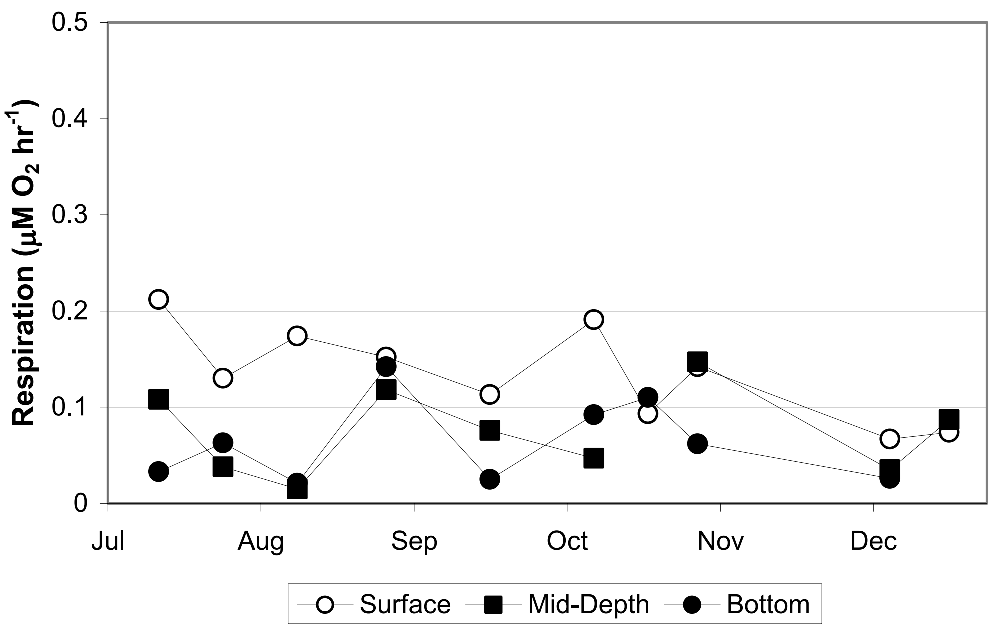



**Figure 5-10. Time series plots of respiration ($\mu MO_2hr^{-1}$) at stations N18 and N04**

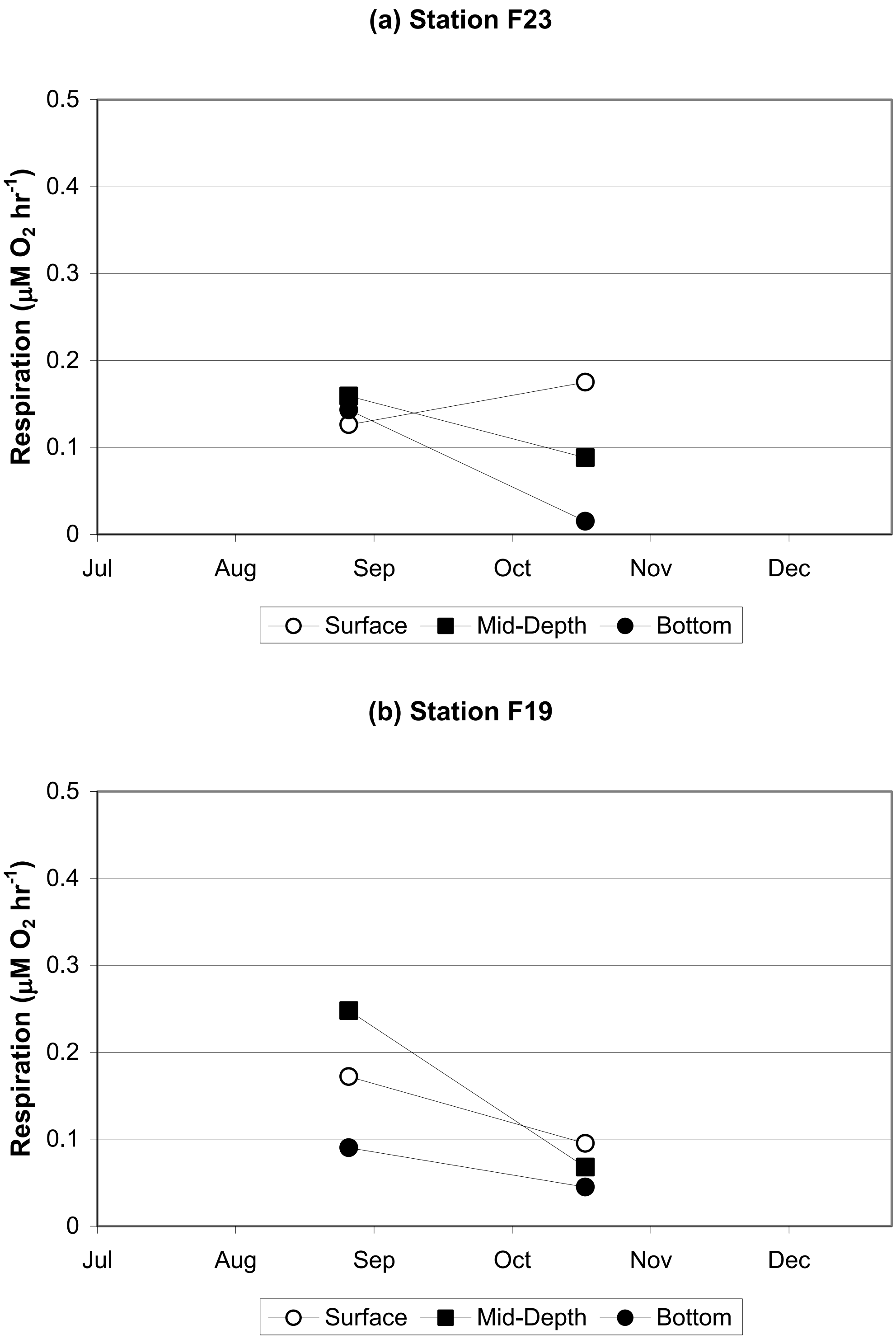



**Figure 5-11. Time series plots of respiration (μ$MO_2hr^{-1}$) at stations F23 and F19**

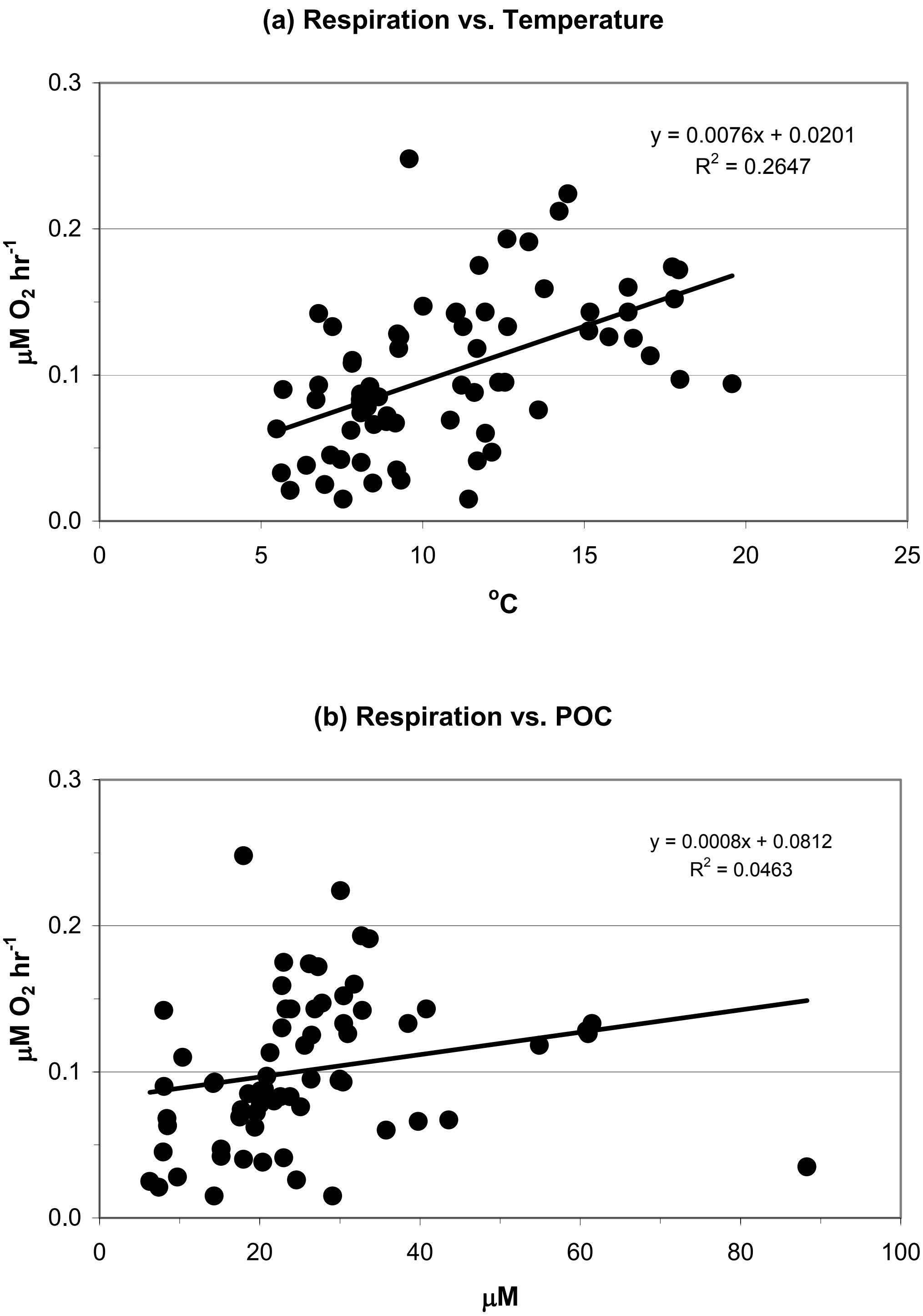



**Figure 5-12. Comparison of respiration rate versus a) temperature and b) POC concentration for data collected at stations N04, N18, F19 and F23 in July – December 2001.**

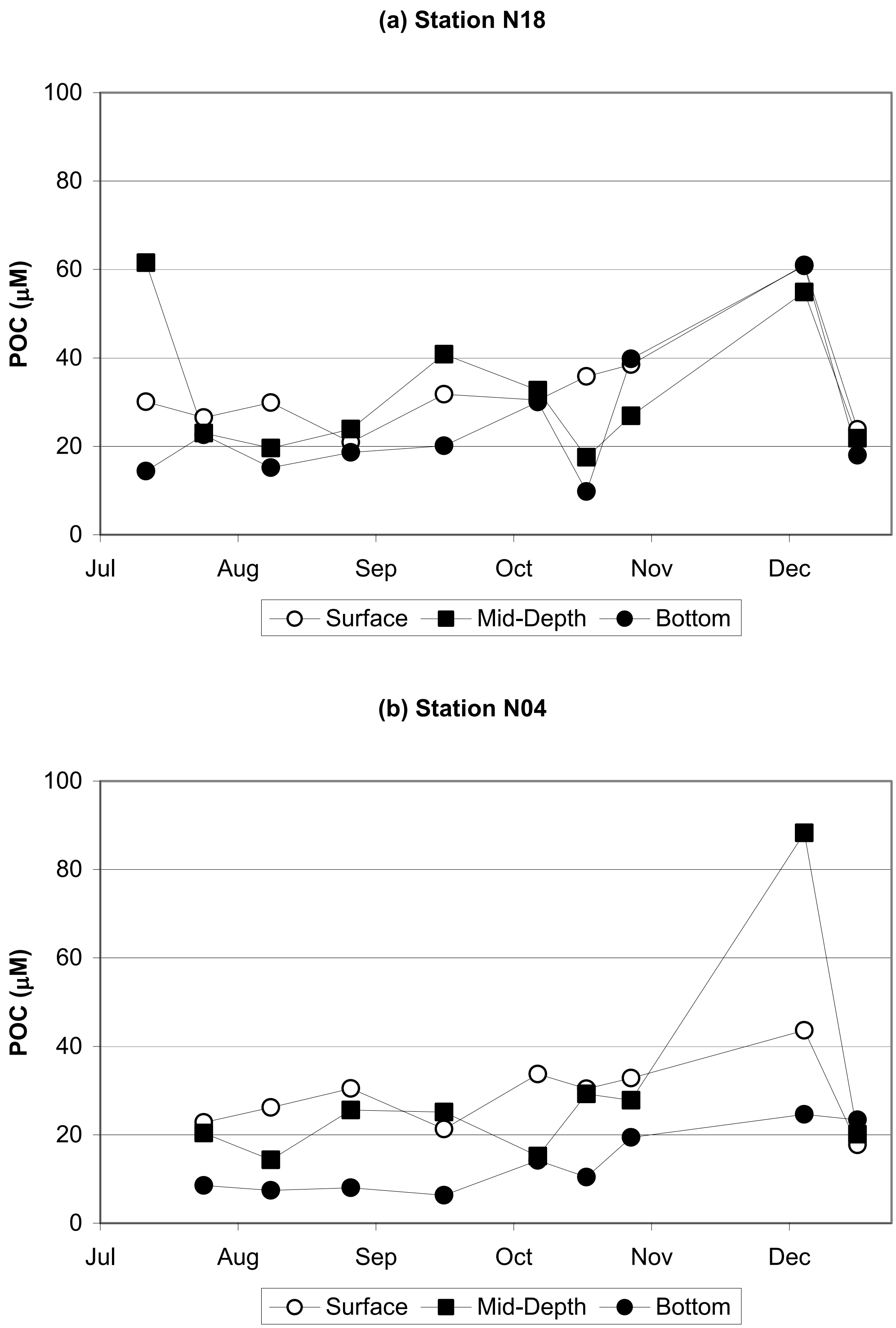
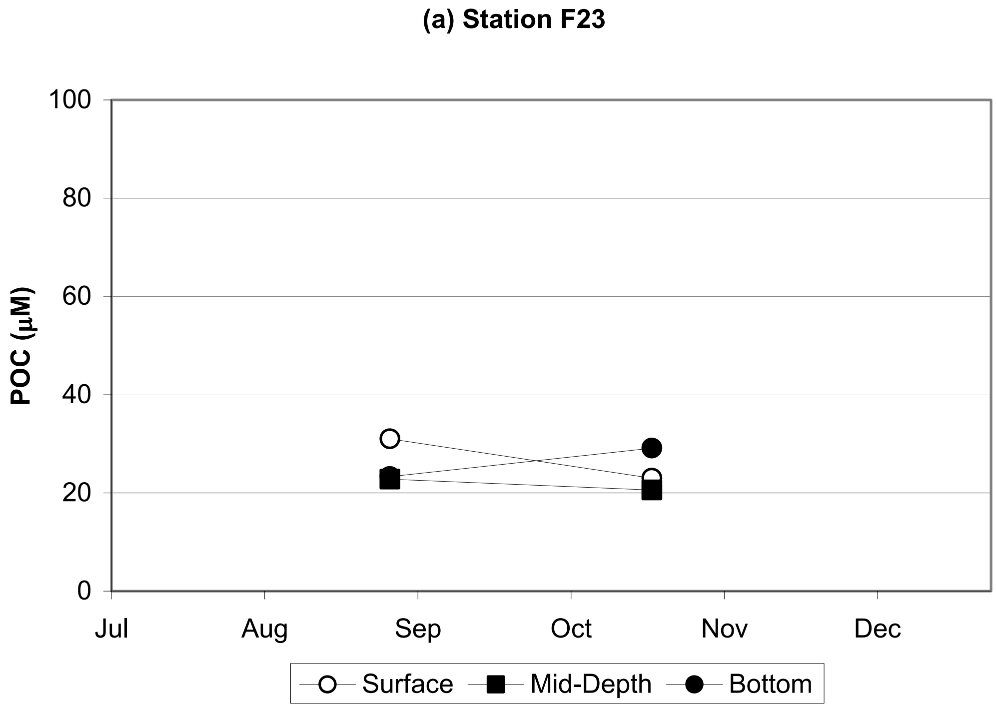



**Figure 5-13. Time series plots of POC (μMC) at stations N18 and N04**



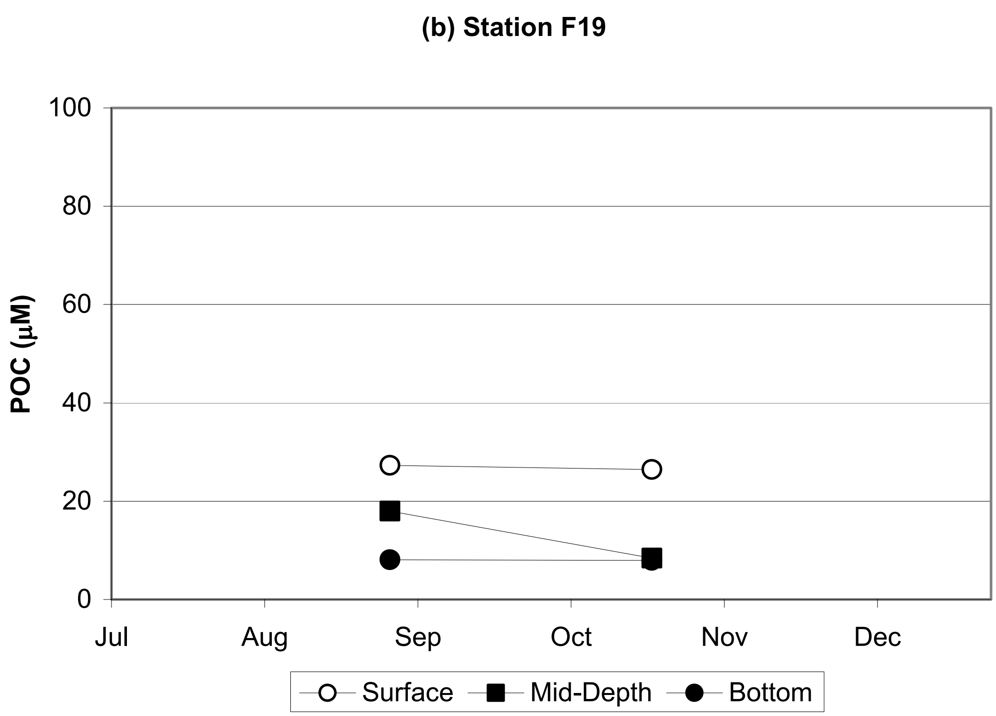
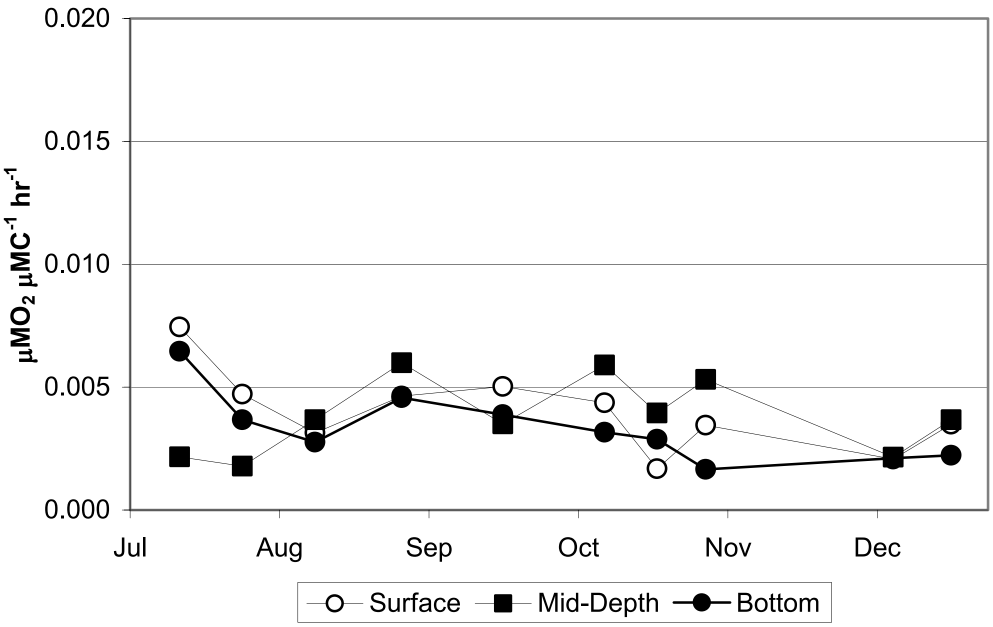




**Figure 5-14. Time series plots of POC (µMC) at stations F23 and F19**

**(a) Station N18**




**(b) Station N04**

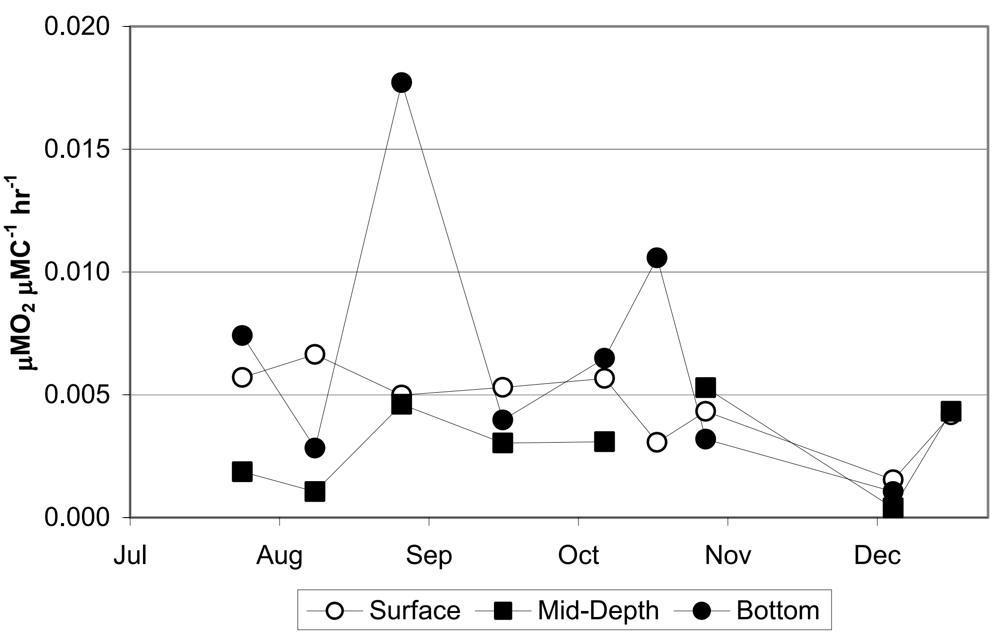



**Figure 5-15. Time Series plots of carbon-specific respiration ($\mu MO_2 \mu MC^{-1} hr^{-1}$) at stations N18 and N04**

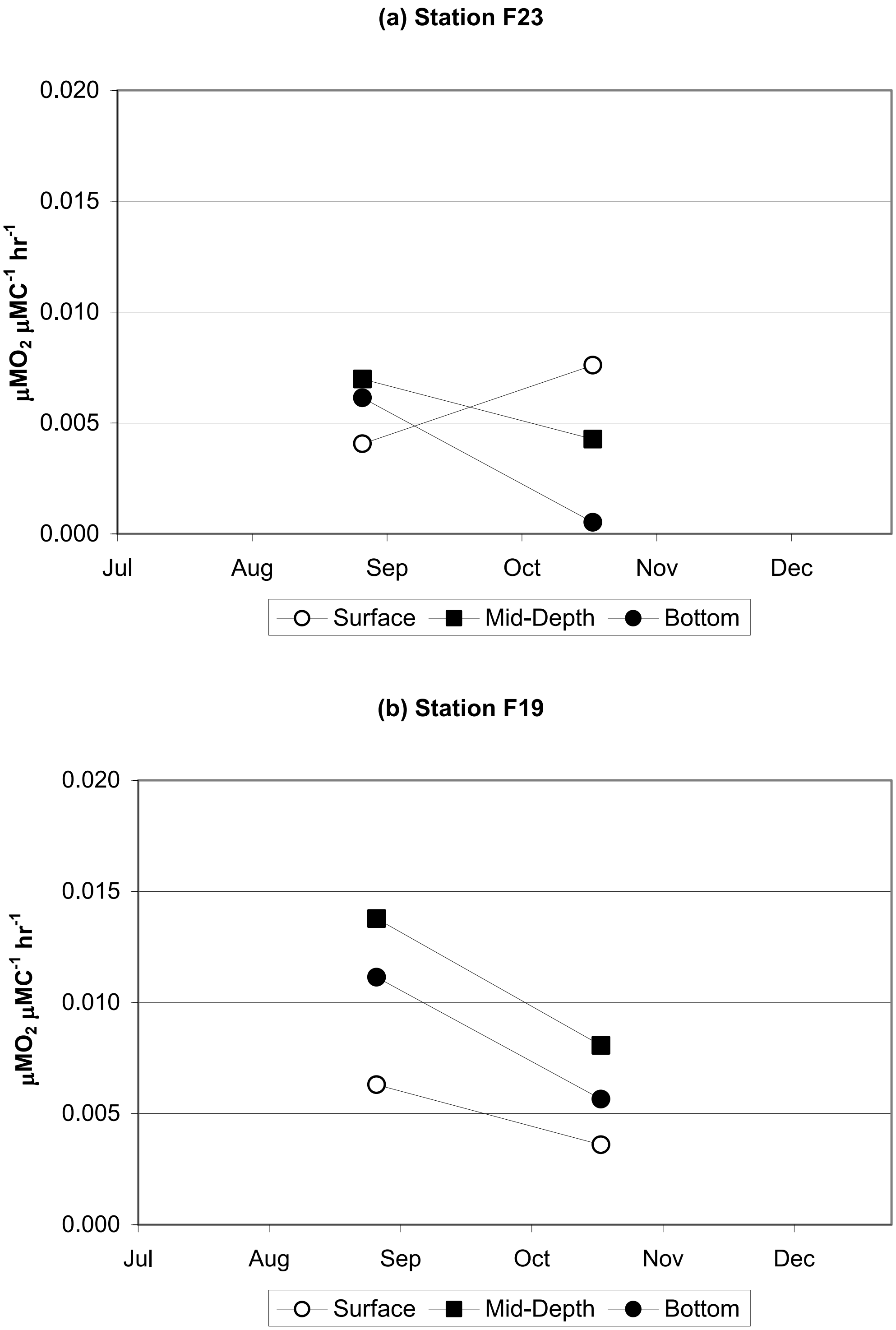



**Figure 5-16. Time Series plots of carbon-specific respiration ($\mu MO_2 \mu MC^{-1} hr^{-1}$) at stations F23 and F19**

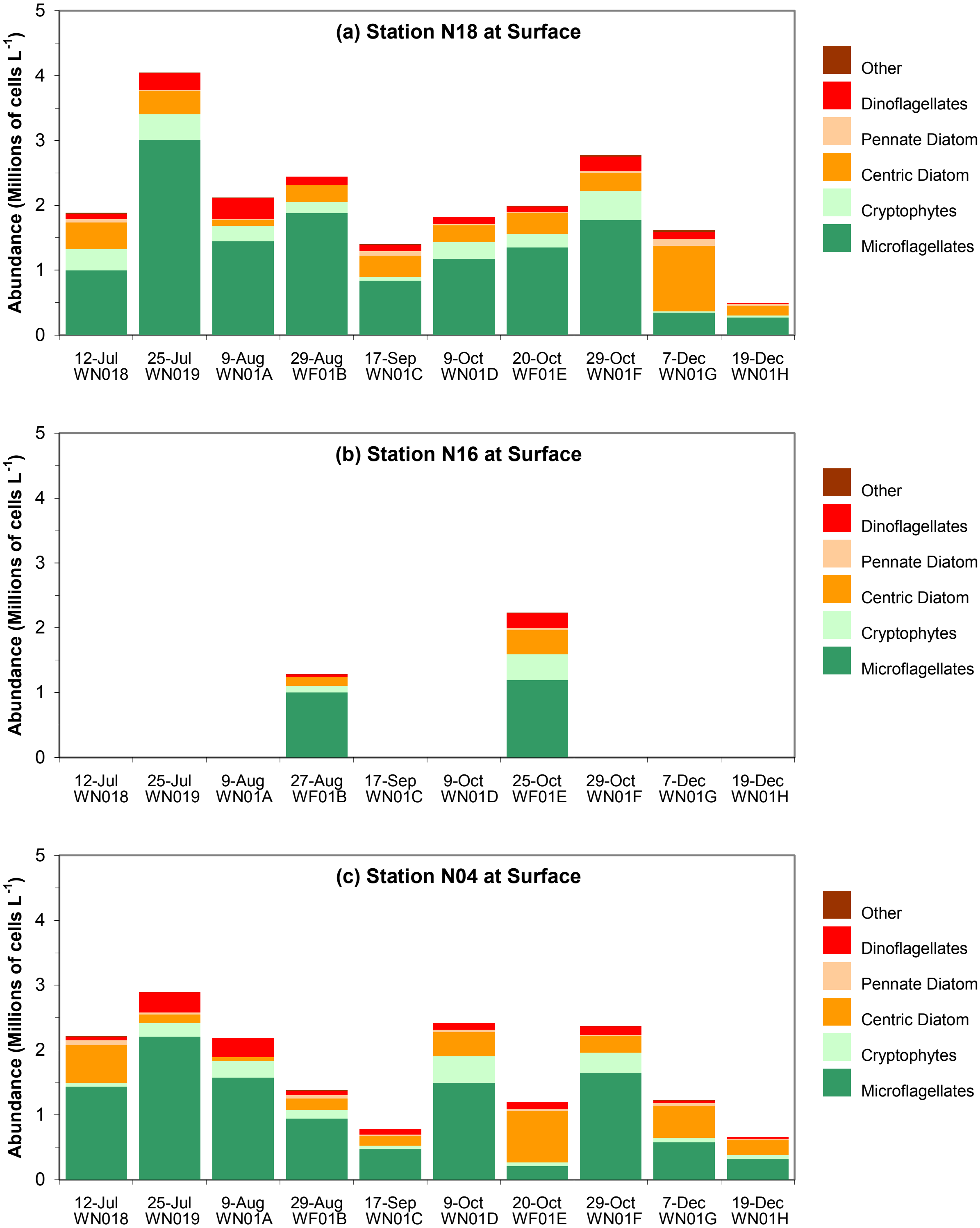



**Figure 5-17. Phytoplankton abundance by major taxonomic group, nearfield surface samples**

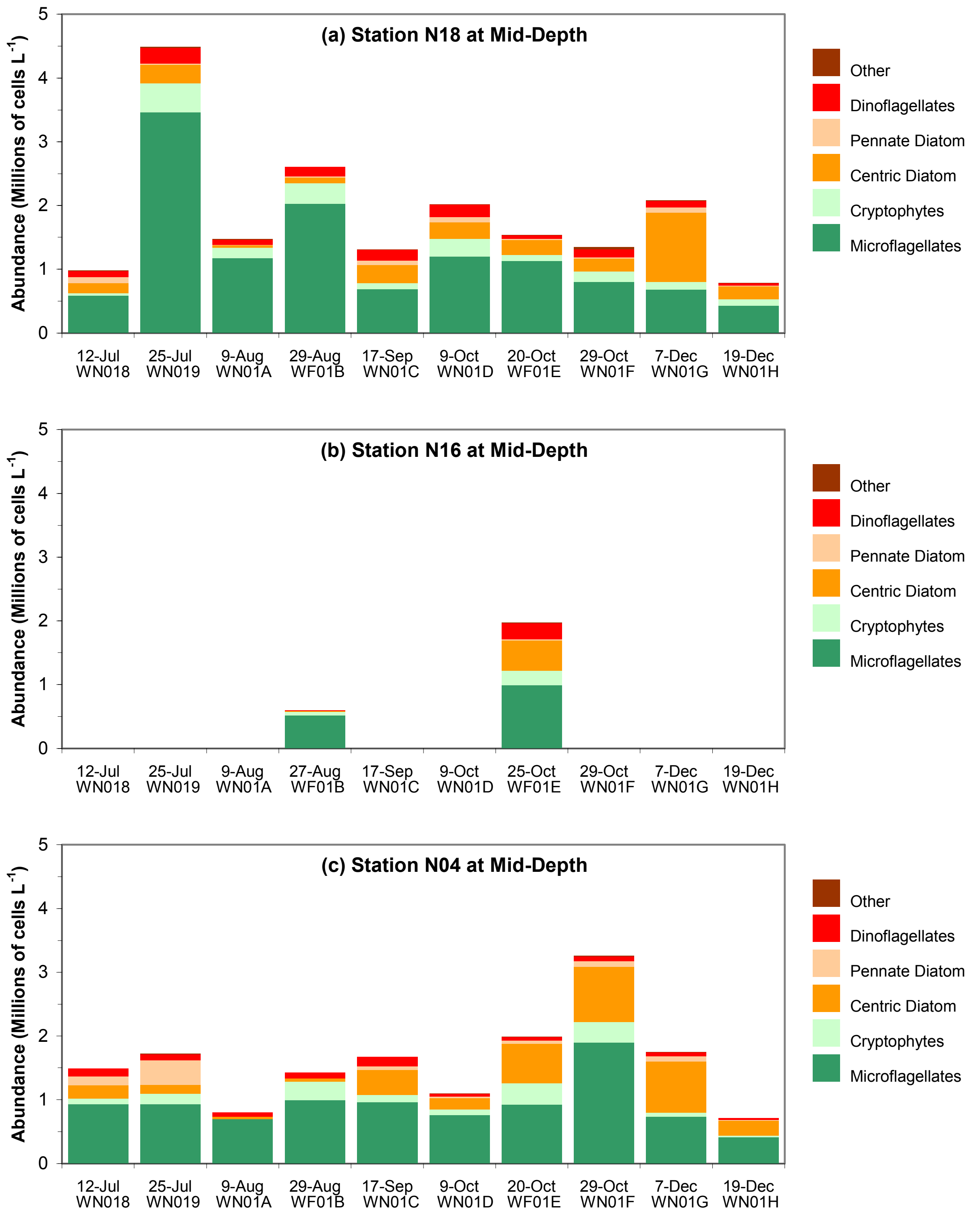



**Figure 5-18. Phytoplankton abundance by major taxonomic group, nearfield mid-depth samples**

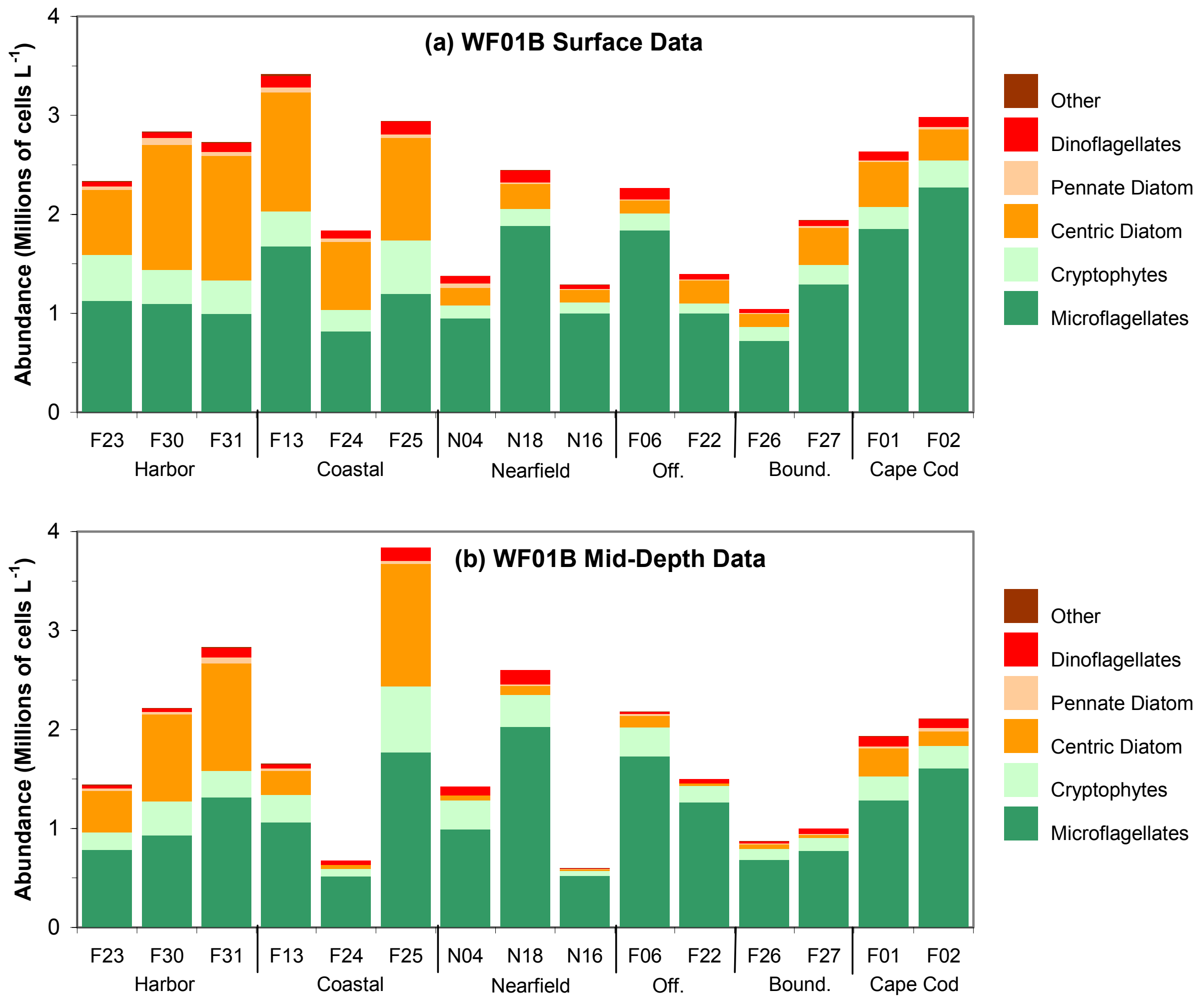



**Figure 5-19. Phytoplankton abundance by major taxonomic group, WF01B farfield survey (August 27 – 30)**

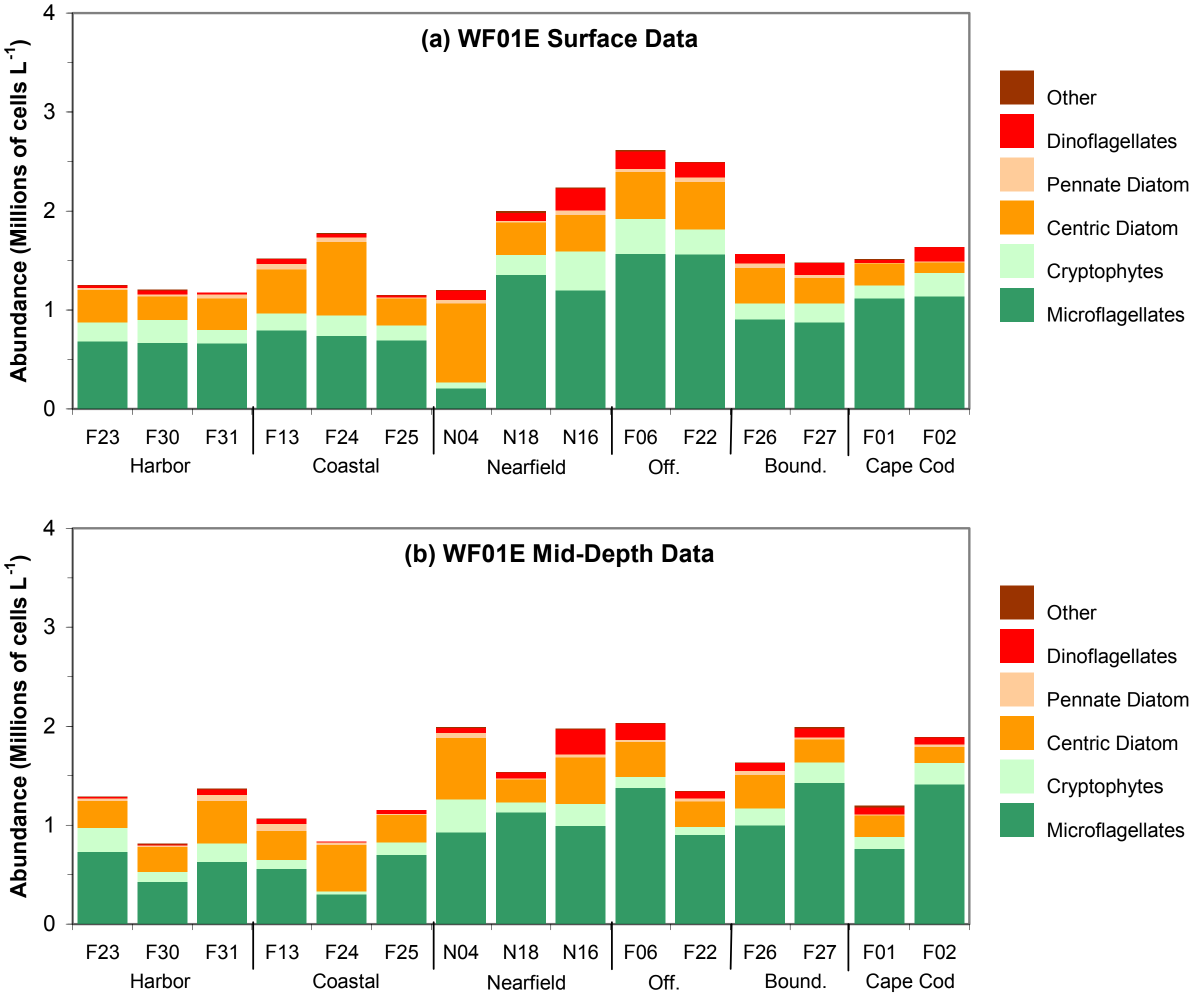



**Figure 5-20. Phytoplankton abundance by major taxonomic group, WF01E farfield survey (October 19 – 26)**

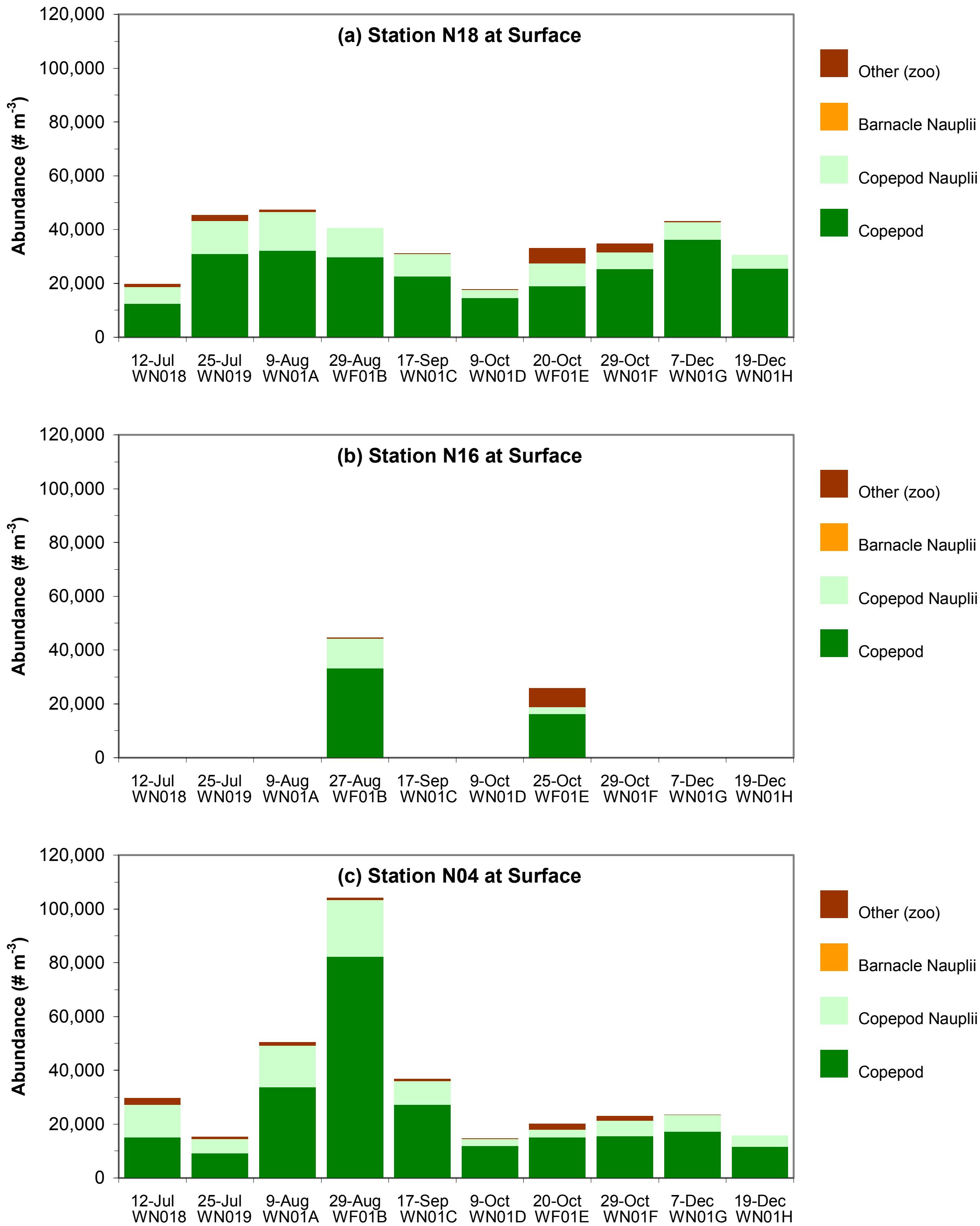
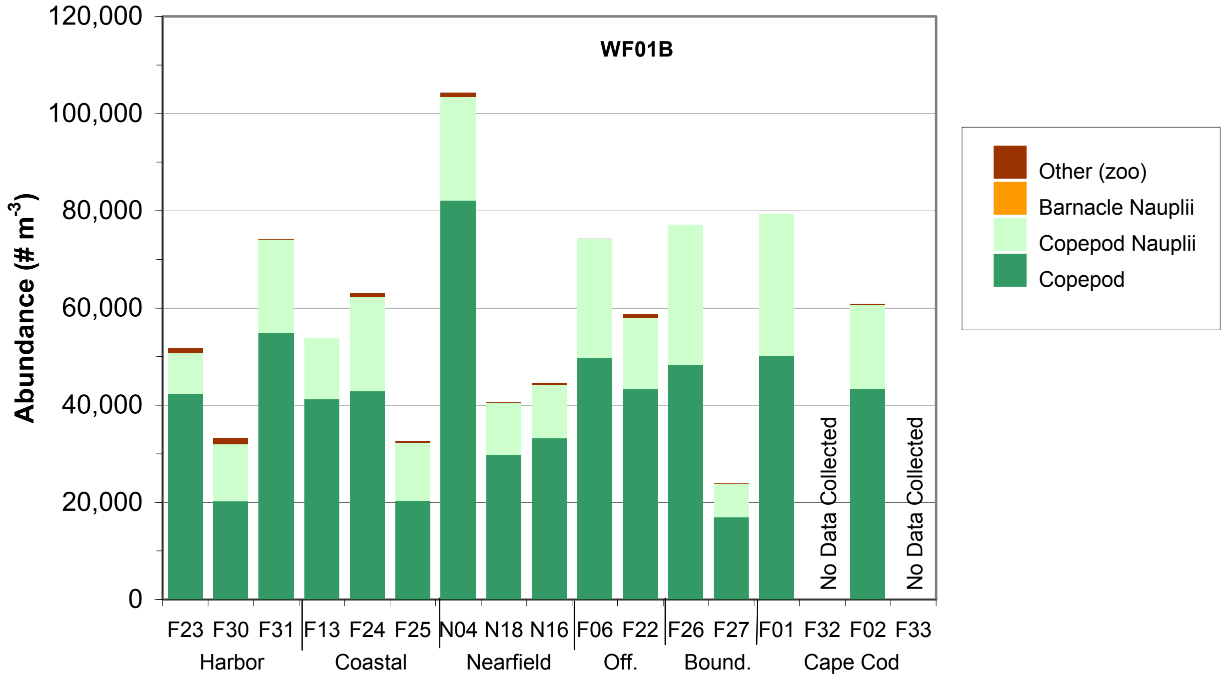



**Figure 5-21. Zooplankton Abundance by Major Taxonomic Group, Nearfield Samples**



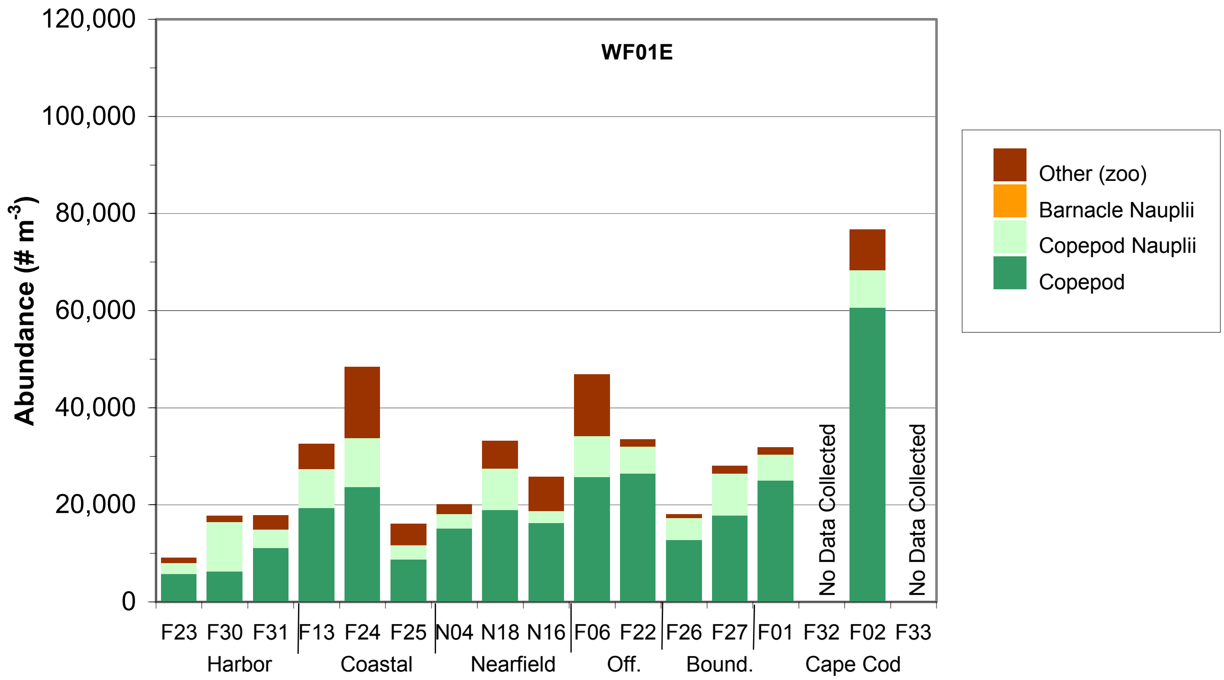




**Figure 5-22. Zooplankton abundance by major taxonomic group (a) WF01B farfield survey (August 27 – 30) and (b) WF01E farfield survey (October 19 – 26)**

# 6.0 SUMMARY OF MAJOR WATER COLUMN EVENTS

The primary physical characteristic of this period was the delay in the overturn of the water column and the return to winter conditions. Regionally, seasonal stratification had deteriorated at the coastal and Boston Harbor stations and had begun to weaken at the offshore stations by the October survey (WF01E). In the nearfield, mooring data indicated that there was a strong mixing event in late September. By early October, however, both the mooring and nearfield monitoring data indicated that although stratification had weakened since the September survey, the water column at all but the most inshore nearfield stations was stratified. A weak density gradient continued to be observed from late October to early December. The water column finally returned to well-mixed winter conditions over the entire nearfield in late December (WN01H). Mild meteorological conditions (infrequent storms, warm dry fall, weak and variable winds) contributed to the lingering stratification into early December. In turn, the weak stratification from October to December allowed for both a steady influx of nutrients to the surface waters and the development of a prolonged late fall/early winter bloom.

The general trend in nutrient concentrations during the 2001 July to December period was similar to previous baseline monitoring years. Nutrients were depleted in the surface waters during the summer due to biological utilization and increased in concentration with weakening stratification and increased mixing. The extended period of weak stratification from October to December still provided a source of nutrients to the surface waters due to weak mixing, supporting the late fall/early winter phytoplankton bloom. The combination of limited mixing and the late fall/early winter bloom kept surface water nutrient concentrations low until the water column became well mixed in late December.

The transfer of MWRA effluent from the harbor to the bay outfall on September 6, 2000 moved the anthropogenic nutrient signal from the harbor offshore to the center of the nearfield. Although it is not a conservative tracer due to biological utilization, $NH_4$ has been shown to be a clear indicator of the effluent plume in the nearfield now that the outfall is online. In August 2001, salinity and $NH_4$ data suggest that the plume was advected from the nearfield to the south. A comparison of contour plots of $NH_4$ and chlorophyll concentrations along the Nearfield-Marshfield transect suggest that the elevated $NH_4$ concentrations in the plume and preferential uptake of $NH_4$ by phytoplankton may have contributed to localized increases in chlorophyll concentrations. An attempt will be made to more quantitatively evaluate this linkage via a simple box model for the 2001 annual water column report.

Chlorophyll concentrations were relatively low during the second half of 2001, but reached unusually high levels during the late fall/winter bloom in early December. The timing and magnitude of the fall 2001 bloom was a departure from the two previous years. During September and October of 1999 and 2000, substantial and prolonged fall blooms were observed. In 2001 there was a minor fall bloom in September and then a more prolonged and substantial bloom was observed in late October and early December. The peak nearfield survey mean chlorophyll concentration was observed in early December and was coincident with high POC concentrations and peak areal production rates of >3250 mg C $m^{-2}$ $d^{-1}$. This was relatively late for the peak production rates and chlorophyll concentrations to be observed. These were the highest December values observed since baseline monitoring began in 1992. However, areal production was higher at station N04 in comparison to station N18 from early October to early December, which is a deviation from the spatial trend in production observed during previous years. At station N18, the mean and maximum productivity at the bottom depths was greater than prior years, although a similar increase in bottom productivity was not noted at station N04.

There was relatively good agreement between the chlorophyll data from the monitoring program and SeaWiFS imagery for the fall of 2001. The SeaWiFS data provided information on a relatively short-term chlorophyll event in early September that was not captured directly by the monitoring program. The imagery also provided confirmation that the elevated chlorophyll concentrations observed in both October and December had continued during the intervening period. These images along with the USGS mooring data provide a valuable source of information between surveys.

Total phytoplankton abundances in the whole water samples were highest in late July, decreasing somewhat through August and October, and declining to lower levels in December. The decrease in phytoplankton abundance from fall to early winter is typical for this time of year. However, in comparison to previous years, the late fall and early winter abundance levels were relatively high. Levels of $>10^6$ cells $L^{-1}$ in the nearfield (mostly centric diatoms) from October to early December were coincident with high chlorophyll concentrations and primary production rates. The high chlorophyll levels recorded for late November to early December by SeaWiFS was coincident with the increased abundance of these large chain-forming diatoms and elevated production rates. There were no confirmed blooms of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during this time period.

Zooplankton abundance reached annual maximum levels in late August and progressively declined through September and October into December. Zooplankton abundance was, as usual, dominated by copepod nauplii and adults and copepodites of the small copepods *Oithona similis*, and copepodites of *Pseudocalanus* and *Centropages* sp., with lesser contributions, at some stations, by meroplankters such as bivalve veligers and, in Boston Harbor, *Acartia* spp. copepodites and adults. Zooplankton abundance in Boston Harbor reached unprecedented low levels during October 2000 likely due to decimation of zooplankton populations by ctenophore (*Mnemiopsis leidyi*) predation. This did not occur in fall of 2001.

The bottom water DO survey minimum values were relatively high and comparable to those measured in the fall of 2000. It might be expected that 2001 DO values would be high given the relatively low chlorophyll concentrations measured in 2001 and presumed low level of organic loading to the bottom waters and benthos. The fact that similar DO minima were observed in two very different 'biological' years – major spring and fall blooms in 2000 and minor blooms in 2001 – suggests that either loading plays a relatively minor role in controlling bottom water DO or that the presumption that high chlorophyll concentrations are indicative of high loading is incorrect. An examination of the connection between physical oceanographic conditions and DO concentrations suggests that it is the former (Geyer *et al*., 2002). It should be noted, however, that even though 2001 DO minimum concentrations were relatively high, bottom water DO concentrations did not increase to typical winter values until late December because of persistent stratified conditions.

September 6, 2000 marked the end of the baseline period, completing the data set for MWRA to calculate the threshold values used to compare monitoring results to baseline conditions. The water quality parameters included as thresholds are annual and seasonal chlorophyll levels in the nearfield, dissolved oxygen concentrations and percent saturation in bottom waters of the nearfield and Stellwagen Basin, and nuisance algae (*Alexandrium*, *Phaeocystis*, and *Pseudo-nitzschia*). Even with elevated chlorophyll concentrations from late October to early December the fall nearfield mean areal chlorophyll value was about half (85 mg $m^{-2}$) that of the fall threshold value (161 mg $m^{-2}$). This continued the trend of relatively low chlorophyll concentrations that had been noted for the first half of 2001. The low concentrations from February to December resulted in summer and annual mean areal chlorophyll values (45 and 67 mg $m^{-2}$) that were also well below threshold levels (80 and 107 mg $m^{-2}$). The DO concentration survey mean minimum for the fall of 2001 was well above the threshold standard for both the nearfield and Stellwagen Basin. The percent saturation values were slightly below the caution threshold of 80% in each area, but were well above the background values and there were no DO concentration or percent saturation threshold exceedances in the fall of 2001.

There were no confirmed blooms of harmful or nuisance phytoplankton in Massachusetts and Cape Cod Bays for July – December 2001. *Phaeocystis pouchetii*, which often blooms during the spring and was observed in April 2001, was not recorded during this period. *Alexandrium* spp. were only observed in July at an abundance of 2.6 cells $L^{-1}$ well below the threshold abundance of 100 cells $L^{-1}$. There were no incidences of shellfish toxicity associated with *Alexandrium tamarense* in Massachusetts and Cape Cod Bays in 2001. The *Pseudo-nitzschia "pungens*" threshold designation can include both non-toxic *P. pungens* as well as the identical-appearing (at least with light microscopy) domoic-acid-producing species *P. multiseries* and since resolving the species identifications of these two species requires scanning electron microscopy all *P. pungens* and *Pseudo-nitzschia* unidentified beyond species were included in the threshold. This grouping of *Pseudo-nitzschia* was observed during many of the surveys from July to December 2001, but at low abundances well below threshold values. The potentially toxic diatom *Pseudo-nitzschia pseudodelicatissima*, however, was present and frequently abundant throughout much of the area over this time period. This species is not currently included in the calculation of the *Pseudo-nitzschia "pungens"* threshold and it is unclear whether abundances of *P. pseudodelicatissima* above the current threshold levels should cause alarm. MWRA and HOM3 scientists are currently reviewing the inclusion of *Pseudo-nitzschia pseudodelicatissima* and additional *Pseudo-nitzschia* species in the MWRA threshold calculation.

A number of topics were called out in this report that will be discussed in greater detail in the 2001 annual water column report including the following:

- Examine physical oceanographic conditions in the summer and fall of 2001 including upwelling/downwelling favorable conditions, the apparent late September mixing event, and the impact of low riverine flows and precipitation during the drought in fall 2001.
- Explore the use of $NH_4$ concentration and flow data for the MWRA effluent discharge in concert with Massachusetts Bay to estimate dilution rates and more quantitatively evaluate this linkage between elevated $NH_4$ concentrations in the plume and higher chlorophyll concentrations via a simple box model.
- Obtain and evaluate chlorophyll data from the USGS mooring for October – December 2001 to provide additional insight into the duration and magnitude of the atypical late fall/early winter bloom of 2001.
- Evaluate the atypical patterns that were observed in productivity including – the delay in peak productivity until early December, the increase in station N04 production relative to station N18, and the relatively high bottom water productivity that was measured at station N18 – none of which had been observed during previous years.

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